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Bone accrual over 18 months of participation in different loading sports during childhood and adolescence

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Mini-abstract

This study investigated the association of impact and non-impact sports on bone mineral density accrual in adolescents for 18 months. The impact sports were beneficial for the bone health (accrual of bone density), on the other hand, swimmers had similar and lower bone mineral density compared to the control group.

Abstract

Purpose: To investigate the association of impact and non-impact sports on bone mineral density (BMD) accrual in adolescents of both sexes over a period of 18 months. **Methods:** The sample was composed of 71 children and adolescents, aged 9 to 17 years at baseline. Bone outcomes were compared according to sports (impact, n=33 [basketball, karate, and judo], non-impact, n=18 [swimming], and control group, n=20). aBMD was measured by Dual-energy X-ray absorptiometry (DXA) and bone mineral apparent density (BMAD) estimated through equation. The statistics analysis was composed by Analysis of variance (ANOVA and ANOVA repeated measures). **Results:** Adjusted aBMD at lower limbs, whole body less head (WBLH) and adjusted BMAD at WBLH were significantly greater in the impact sports group than the non-impact sport group at all time points, besides in 9 and 18 months in upper limbs and total spine at baseline. Non-impact sports group also presented lower values of aBMD compared to control group in lower limbs and WBLH at 9-months and at 9 and 18-months in BMAD WBLH. There was a significant interaction (time x sports group) at upper limbs ($p=0.042$), WBLH ($p=0.006$) aBMD and BMAD WBLH ($p<0.001$). **Conclusion:** Overall, impact sports were more beneficial on accumulating BMD over a period of 18 months, while swimmers had similar and lower BMD compared to the control group.

Keywords: Bone development; Longitudinal; Physical activity; Sports training Youth; Bone density.

Introduction

The first two decades of life seem to be extremely important for bone acquisition for bone acquisition. According to the literature, around 50% of whole body bone mineral content (BMC) is acquired during childhood and adolescence [1], especially among from the years surrounding peak height velocity [2]. Increased gains in bone mineral density (BMD) during adolescence may decrease the risk of developing osteoporosis [3] by achieving the full potential of peak bone mass.

The growth of bone tissues is largely determined by non-modifiable factors, such as genetics and hormones [4, 5]. However, environmental factors, such as physical activity and nutrition, can alter BMC and BMD during growth [6–8]. The positive effects of physical activity on bone health can be supported by an increased action of anabolic hormones and proteins, such as growth hormone (GH) and insulin-like growth factor 1 (IGF-1) [9, 10]. Moreover, physical activity can induce positive bone adaptations via muscle contractions performed during movements that can generate strain and stimulate bone matrix by modifying geometry and strength of trabecular and cortical bones according to muscle-bone unit theory [10, 11]

Among the different manifestations of physical activity, sports participation offers numerous physiological benefits [12] and accounts for a large part of physical activity during childhood and adolescence worldwide [13]. Sports can be considered as impact and non-impact based on the review developed by Tenforde & Fredericson (2011) [10], which characterizes modalities of impact, those that involve ground-reaction forces. In contrast, non-impact modalities are performed in "hypogravity" environments, without ground-reaction forces.

The loading of skeleton during specific sport practice is a key component of the bone adaptations, but the magnitude of the stimuli depends on the training environment (e.g., hard surface, such as basketball, or hypogravity environment, such as swimming) [14, 15], the frequency (e.g., sessions and days per week), intensity (e.g., light, moderate, vigorous) and volume (e.g., sets, repetitions) of each sport [16]. However, a recent review by Bielemaan et al. (2013) indicated the lack of a consensus on which type of exercise performed in early life can most effectively promote bone health [17]. Considering the amount of bone mass acquired during childhood and adolescence [2], and that the majority of children and adolescence engaged in different types of sports, it is of great interest to determine the long-term association of different loading sports and bone acquisition during this period of life.

Based on the absence of consensus about the role of different sports and bone growth, cross-sectional studies have sought to identify the association between different types of sports, such as volleyball [18], football [7], basketball [19], tennis [20], martial arts [21] and bone outcomes compared to controls and other sports. Longitudinal studies enable researchers to assess more appropriately causality than cross-sectional studies, but there are only a few longitudinal studies focusing on the association of different loading sports and bone development [22, 23]. Most of studies in the literature analyzing the longitudinal impact of sports participation in bone density of adolescents were developed up to 12-month of follow-up [24–26]. In fact, a smaller number of studies followed adolescents over 12 months, but those studies have focused in comparisons based on “one single sport versus control group”, while comparisons according to weigh-bearing characteristics (impact, non-impact sports and control group) were not presented by them [27–29]. These studies also did not ponder a volumetric interpretation of BMD considering the influence of body size, as proposed in the use of bone mineral apparent density (BMAD) [30]. Therefore, it is important to understand more comprehensively the long-term relation of sports participation in different levels of ground reaction force and bone accrual during adolescence.

The purpose of this longitudinal study was to compare the long-term of impact (basketball, karate, and judo) and non-impact (swimming) sports on aBMD and BMAD accrual in children and adolescents over a period of 18 months. It was hypothesized that impact sports will have greater bone accrual compared to non-impact sports.

Methods

Study design

This longitudinal study is part of a large cohort study that was conducted in the city of Presidente Prudente from October 2013 to May 2015. The study was approved by the Ethical Research Committee of the São Paulo State University-UNESP (Process number 02891112.6.0000.5402).

At the beginning of the study in 2013, a cooperation agreement was formed between the Laboratory of InVestigation in Exercise-LIVE and the municipal secretariat of Education and Sports of Presidente Prudente. After explaining the proposal to school principals and sports coaches, the researchers were given formal authorization to start data collection. Children and adolescents not actively engaged in any sport and who were enrolled in the schools of the Secretary of Education were invited to join such as the control group. The athletic group comprised adolescents of the modalities representing their municipality: judo, karate, basketball, and swimming. To participate in the study, adolescents were required to provide informed consent signed by a parent or guardian.

Participants

The inclusion criteria to be eligible were: (1) chronological age between 9 and 17 years at baseline; (2) no current use of medication that could affect bone metabolism, and (3) regular participation in school physical education classes (two hours per week). For sports group: (1) a minimum of 6 months of participation in the specific sport (considering previous studies) [31, 32]; (2) non-involvement in other sports. For control group: (1) the absence of previous engagement in organized and supervised sports before baseline measures (3 months) and during the 18 months of the study.

At baseline, 184 children and adolescents (108 males and 76 females) of both sexes were recruited, after 9 months 126 adolescents (78 males and 48 females) completed the second visit and 71 (42 males and 29 females) children and adolescents completed the third visit over 18 months. The drop out of 113 children and adolescents was mainly due to disinterest in continuing as a volunteer in the study, absence in the scheduled measurement, and moving to another city in control group and interrupting sports participation or being transferred to another team in sports group. The present study included only valid data from the 3-time points (no missing data). Potential selection bias (71 children and adolescents who remained versus those 113 children and adolescents who dropout) was assessed through the differences at baseline. The groups were similar to chronological age (t test; p-value = 0.126), body mass (t test; p-value = 0.072), height (t test; p-value = 0.112), years from PHV (t test; p-value = 0.097), age of PHV (t test; p=value = 0.983), fat mass (t test; p-value = 0.335), lean soft tissue (t test; p-value = 0.322), upper limbs aBMD (t test; p-value = 0.272), lower limbs aBMD (t test; p-value = 0.230), total spine aBMD (t test; p-value = 0.150) and whole body aBMD (t test; p-value = 0.124). Lastly, the drop out predominantly occurred in control group (76.5%) compared to non-impact (40.0%) and impact sports (52.2%) (chi-squared with p value = <0.001).

The present study included only valid data from the 3-time points. The control group comprised 20 children and adolescents (12 males and 8 females). Sports were categorized according to potential osteogenic impact. The impact group comprised 33 children and adolescents: basketball (8 males) and martial arts (11 males and 14 females in karate and judo). Finally, the non-impact group comprised 18 adolescent swimmers (11 males and 7 females) (**figure 1**). Athletes from karate and swimming participated in competitions at the national level and the basketball players participated in state tournaments. The remaining athletes (judo) competed at the regional level.

Previous Sports Participation and Training Routine

The athletes reported the time (in months) of practice. Similarly, coaches provided information about the volume and frequency of training (minutes trained daily and the number of days trained in a week, respectively). Exposure to resistance training was also consulted with coaches and athletes and considered as a confounding factor.

Anthropometry

Stature and sitting height were measured using a stadiometer (Sanny, model American Medical of the Brazil Ltda, Brazil, accurate to 0.1 cm) that permitted an estimate of maturity offset. The body mass was measured using an electronic scale (Filizzola PL 150, model Filizzola Ltda, Brazil with a precision of 0.1 kg). All measures were assessed using standardized techniques by a single trained researcher. The technical errors of measurement were 0.041%, 0.110% and 0.157% for body mass, height, and sitting-height, respectively.

Body Composition and Bone Mineral Density

Areal Bone mineral density (aBMD, g/cm²), lean soft tissue (LST, kg) and fat mass (FM, kg) were measured at the university laboratory in a temperature-controlled room using dual-energy x-ray absorptiometry (Lunar DPX-NT; General Electric Healthcare, Little Chalfont, Buckinghamshire, UK) with GE Medical System Lunar software (version 4.7). A trained researcher performed all scans and tested the scanner quality before the first exam of each day. The coefficient of variation for this device was 0.66% (in whole body BMD analysis, n=30 participants not involved in this study). The scans were performed using a standardized protocol with the participants remaining in the supine position and wearing only light clothing, without shoes. Regional analysis of BMD in upper limbs, lower limbs, total spine (cervical, thoracic and lumbar) and WBLH occurred off-line after the scans took place [33] following the recommendations of manufacturer recommendations and previous studies [34, 35]:

-Upper Limbs: measured considering the position of the line passing through in upper edge of the acromial extremity of the clavicle and the lateral and medial lines defined comprising all soft tissues (the same for right and left sides).

-Lower Limbs: measured considering the position of the line passing through on the lower edge of the ischium and the lateral and medial lines defined comprising all soft tissues (the same for right and left sides).

-Total Spine: Measured from the posterior-superior edge of iliac crest (L4/L5 level) to the lower edge of the chin. The lateral cut positioned as close as possible to the spine.

The bone mineral apparent density (BMAD-g/cm³) was calculated by the equation: $BMAD_{TB}$ = BMC/(total body BA^2/body height) proposed by Katzman et al. [30]. It is an approach that involves the calculation of bone mineral apparent density

(BMAD) by dividing bone mineral content (BMC) by the three-dimensional bone volume derived from its two-dimensional projected bone area (BA).

Somatic Maturation

Anthropometric measurements (body mass, stature, and sitting height) were used to calculate years from the age of peak height velocity (PHV) through mathematical formulas predicted by Moore et al. [36]. This measure denotes the time remaining (years) to reach the age of PHV. Finally, by subtracting chronological age by years from the peak height velocity, it is possible to find the age of the peak height velocity (APHV).

Years from age of PHV for males= -8.128741 + [0.0070346 * (Age * Sitting Height)]

Years from age of PHV for females= -7.709133 + [0.0042232 * (Age * Stature)]

Age of PHV= Chronological age – years from age at PHV.

R^2=0.896 (SEE+0.542) in boys and R^2=0.898 (SEE+0.528) in girls.

Consumption of vitamin D

Utilizing a questionnaire about foods rich in vitamin D (commonly observed in a Brazilian diet) made by a nutritionist. The adolescents reported the frequency of consumption (Likert scale) during the previous week the evaluations. The sum of the generated score was considered proxy of vitamin D intake and inserted in the analysis as utilized in previous studies[24, 31].

Statistical Analyses

The sample was calculated considering bone density gains (sport participant versus non-sport participant) of 0.05 g/cm^2 [24], considering a standard deviation of 0.07 g / cm^2, 80% power and 5% error-alpha. Taking into account all these parameters, the minimum sample size was estimated in 15 children and adolescents in each group.

Following checks for data distribution, the descriptive analyses were reported in mean and standard deviation (SD), as well as appropriate 95% confidence levels. Analysis of Variance - ANOVA was performed for initial comparisons between groups using Bonferroni post-hoc test. ANOVA- repeated measures (3 groups x 3 time points) was used for comparisons in aBMD accrual at different skeletal sites after adjustment for APHV, LST of the specific site, volume of training, practice of resistance training (Categorical variable [yes or no]), sporting experience (months), fat mass, height, vitamin D intake and sex [23, 37] and the differences among groups observed through confidence interval. The statistical analyses were performed using BioEstat (version 5.0) and the significance level was set at p-value<0.05.

Results

Table 1 shows participants´ descriptive characteristics at baseline by sport. Seventy-one children and adolescents (42 males and 29 females) with valid data on the three-time points were included. Control group showed significantly lower values for height (p=0.041) and LST (p = 0.001) than the non-impact group and lower LST also compared to the impact group (p = 0.014). In addition, the non-impact group presented a higher volume of training than the impact group (weekly training) (p=0.001). Comparisons of aBMD showed similar values among all groups at the total spine. However, the impact group had significantly higher aBMD at the upper limbs (p=0.033), lower limbs (p=0.019) and WBLH (p=0.019) than the control group **(table 1**). Lastly, non-impact sports showed lower BMAD of WBLH than impact sports (p=0.038) and also control group (p=0.027).

The non-impact group presented significantly lower values of aBMD at the upper limbs **(Figure 2, Panel A)**, compared to the impact group at 9 months (mean of 0.751 in non-impact sports vs. 0.828 in impact sports) and 18 months (mean of 0.782 in non-impact sports vs. 0.869 in impact sports). Furthermore, the control group presented lower of aBMD at the upper limbs compared to the impact group in baseline (mean of 0.699 in control group vs. 0.770 in impact sports) and 18 months (mean of 0.795 in control group vs. 0.869 in impact sports).

Furthermore, there were significant differences in aBMD at lower limbs between groups **(Figure 2, Panel B),** the non-impact group had significantly lower values compared to the impact group in the three moments (mean of 1.063 vs. 1.179 at baseline; mean of 1.112 vs. 1.234 in 9 months and 1.153 vs. 1.295 in 18 months in non-impact and impact sports, respectively) and lower values compared to the control group in 9-months (mean of 1.112 in non-impact vs. 1.226 in control group). Regarding aBMD in total spine, the impact group presented significantly higher values compared to the non-impact group at baseline (mean of 0.891 in non-impact vs. 0.974 in impact sports) **(Figure 2, Panel C)**.

The non-impact sports group had significantly lower aBMD adjusted values in the WBLH when compared to both the control group and impact sports at 9 months (mean of 0.935 in non-impact vs. 1.037 in impact sports and 1.037 for control group) and with the impact group at baseline (0.908 in non-impact vs. 0.992 in impact sports) and 18-months (0.977 in non-impact sports vs. 1.096 in impact sports) **(Figure 2, Panel D)**. There was a significant interaction between "time*sport" at the upper limbs (p = 0.042) and the WBLH (p = 0.006) aBMD. The sport practiced significantly affected all bone variables (upper limbs, p = 0.001, lower limbs, p = 0.001; total spine, p = 0.013; WBLH, p = 0.001) over the 18-month studied period.

When analyzing BMAD of whole body, more expressive differences were observed between the groups. The non-impact group showed significant lower values compared to the impact group and control group in 9 months (mean of 0.081 in non-impact sport vs. 0.094 in control group and 0.091 for impact sports) and 18 months (mean of 0.081 vs. 0.091 and 0.031 for non-impact, control group and impact group, respectively) and the impact group at baseline (mean of 0.085 in non-impact sport vs. 0.093 in impact group) **(Figure 3)**. The time (p=0.002) and sport practiced (p<0.001) significantly affected the BMAD, as well there was a significant interaction between "time*sport (p<0.001).

Discussion

The main findings of the present study indicate that children and adolescents involved in impact sports, such as basketball and marital arts, over a period of 18-months have significantly higher adjusted aBMD and BMAD accrual compared to non-impact sports, such as swimming. Furthermore, swimmers also have a significantly lower aBMD and BMAD accrual at the WBLH and lower limbs compared to the control group.

These findings might be explained due to: 1) the specific training characteristics of each sport [11, 25]; 2) the different forces continuously applied to the skeleton over a long period of time [10, 38, 39].

Understanding the association of sports participation and bone health during adolescence has been debated in the literature [24, 40, 41]. The findings of the present study show that participation in impact sports, such as basketball and martial arts, affects differently the aBMD and BMAD accrual of which they found to have higher aBMD and

BMAD compared to adolescents practicing non-impact sports, such as swimming. These results confirmed our hypothesis that the impact sports are beneficial for aBMD accrual [25]. Prolonged exposure in impact sports can increase the mechanical loading on the bone matrix. Sports modalities, such as basketball and martial arts (modalities of our study) involve movements, such as jumps, sprints, changes of direction, high impact and start stops. These movements generate compressions and tensions in the bones [11, 39] generating a process of metabolic stress and consequently stimulating bone formation [10, 38].

A study of Zribi et al assessed bone outcomes in prepubescent adolescent basketball athletes aged 11.1 years compared to controls [19]. It was found that basketball players had significantly higher BMC at upper, lower limbs and WBLH than controls, which is in accordance with the results of the current study. A different study of Ito et al showed that 9-months of judo participation improved significantly aBMD accrual compared to controls in males aged 12.9 years [42]. Furthermore, previous evidence shows that bone adaptations are site-specific, according to the skeletal sites stimulated by the sport specific patterns [43]. Previous studies indicate that the skeletal sites most benefited by the practice of the specific sport are those directly stimulated, such as legs aBMD in basketball players [24], arms BMD for judo fighters [21], dominant foot in adolescent footballers [7] and dominant arm in tennis players [20].

Results from the current study are also supported by a recent cross-sectional study involving adolescent football, swimming and cycling adolescent male athletes [44]. The study concluded that adolescent males involved in weight-bearing sports, such as football, had higher bone mass, bone geometry, and bone stiffness than those involved in non-weight bearing sports, such as swimming and cycling. The same study found that swimming and cycling adolescent athletes presented similar bone status with an active control group, and the authors called for more longitudinal studies to understand the association of the ‘non-osteogenic' sports participation and bone accrual during growth, which was investigated in the current study.

In the present study, the swimmers presented significantly lower aBMD and BMAD compared to the impact sports athletes in most skeletal sites and at all three time points (except at baseline at the upper limbs) and in BMD of lower limbs (9-months), WBLH (9-months) and BMAD of WBLH (9-months and 18-months) compared to control group. Interestingly, in a systematic review and meta-analysis by Gomez-Bruton et al [45], analyzed the effect of swimming during childhood and adolescence and found lower values of BMD in swimmers compared to weight-bearing sports. These results corroborate our findings, however, the systematic review also concluded that swimmers show similar values of BMD compared to the control group, unlike the results of our study. Considering that the meta-analysis counted only one longitudinal study, due to the absence of longitudinal studies in the literature, the long-term swimming practice during adolescence may cause lower bone development compared to controls, as found in the present study.

Interestingly, the study of Vlachopoulos et al. (2018) [25] found similar results of BMD among swimmers and control group, however, this study was developed with a shorter duration (12 months) and the average weekly training of swimmers was 9.4 hours at baseline while our swimmers practiced 16.6 hours per week. The longer time in training (without impact) could explain the lower values of aBMD and BMAD (WBLH) compared to the control group in our study. Finally, it is important to highlight that the use of bone mineral apparent density (BMAD) allows a more precise analysis of the results, mainly because considers the height of the adolescents, variable which affects comparisons using the areal bone mineral density.

In our sample, swimmers presented significantly higher values of lean mass than controls and the literature has emphasized a positive relationship between lean mass and aBMD, even in swimmers [16, 46]. For this reason, adjustments were made by lean mass in order to specifically analyze the association of sports participation and aBMD/BMAD by removing the effect of lean mass. Thus, the present findings indicate that participation in "hypogravity" environment without gravitational loading, such as swimming, may have negative association with WBLH bone development despite the higher lean mass values [40].

The results of our study were similar with the literature in terms of bone adaptations in skeletal segments (upper and lower limbs) and it highlights the hypothesis that swimming has a non-osteogenic effect in both upper and lower limbs. A recent study by Agostinete et al. [16] focusing on the impact of the training load on the bone health of swimmers, found a negative relationship between lower aBMD at limbs and total body with training load, but not in upper limbs in adolescent swimmers of both sexes. During swimming practice, most of the movements are produced in the horizontal plane, producing forces mainly from the upper limbs, thus reducing the function of the lower limbs only for stabilizing [47]. The forces concentrated in the upper limbs might activate muscle-bone unit to respond differently. Another study developed by Greene et al. [48] in female adolescent water polo athletes strengthens this hypothesis by indicating that there were no significant benefits in bone structure in water polo athletes compared with controls at the lower limbs while in the upper limbs, adolescent female water polo athletes had greater bone strength index at the distal radius compared to non-active girls. The swimming training routine may be related to inhibition of the GH / IGF-1 axis and increased inflammatory markers in the bloodstream generating catabolic responses in bone tissue [49].

The strengths of this study include the longitudinal follow-up of 18 months in different sports groups. The limitations should also be acknowledged. Firstly, we adopted as inclusion criteria the non-engagement in organized and supervised sports for a minimum period of three months, which is sufficient detraining for significant reductions in physical capacities [50], however, it is plausible that this period should be not sufficient for deficits in exercise's adaptations on BMD. In addition, the minimum sample size was reached only when both sexes are gathered, limiting sex-specific analyses, as well as analysis considering specific sports (impact sports group gathered different sports assuming they have similar mechanical loading [basketball, karate, and judo]). Finally, prolonged exposure in intensive training sessions during growth can be associated with a reduced habitual physical activity practice compared to non-active adolescents as previously analyzed by the literature in swimmers [51], which was not assessed in the present study.

In summary, the present study indicates that children and adolescents engaged in impact sports (basketball and martial arts) accumulate significantly higher aBMD and BMAD compared to children and adolescents engaged in non-impact sports (swimming) over a period of 18 months. Moreover, swimmers had similar values compared to the control group in upper, total spine, and significantly lower limbs, aBMD and BMAD of WBLH compared to the control group. These findings suggest that long-term participation in swimming may not be beneficial for bone health.

Most studies in the literature focusing on analysis of different sports modalities on bone health are cross-sectional in design. This cohort study followed children and adolescents for 18 months and indicates that those who were engaged in non-impact sports presented lower aBMD and BMAD accrual compared to those one who were engaged in impact sports. These findings hint that it is important of weight-bearing exercises on training routines in order to promote bone health.

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Table 1. Descriptive characteristics of the sample stratified by sports at baseline (n=71)

	Control Group (n= 20, 12 males) Mean (SD)	Non-Impact sport (n=18, 11 males) Mean (SD)	Impact Sports (n=33, 19 males) Mean (SD)	p-value
Chronological age (years)	12.6 (2.6)	12.7 (1.2)	12.7 (1.3)	0.955
Body mass (kg)	46.6 (12.4)	53.7 (11.2)	53.7 (14.7)	0.134
Height (cm)	153.9 (11.6)	164.0 (10.5)[a]	159.8 (13.9)	0.049
Years from PHV (years)	-2.7 (1.2)	-1.9 (1.7)	-2.3 (1.6)	0.290
APHV (years)	15.4 (2.1)	14.8 (1.3)	15.0 (1.2)	0.459
Lean soft tissue (kg)	30.3 (6.7)	40.8 (8.6)[a]	37.5 (9.7)[a]	**0.001**
Fat mass (kg)	13.2 (7.4)	9.8 (4.8)	14.1 (9.8)	0.197
Fat mass (%)	27.2 (10.0)	18.1 (7.3)[a]	23.4 (9.7)	**0.014**
fat mass of trunk (%)	28.5 (10.7)	19.9 (8.0)[a]	25.4 (10.6)	**0.032**
Areal bone mineral density (g/cm^2)				
Upper limbs	0.685 (0.077)	0.750 (0.071)	0.766 (0.142)[a]	**0.039**
Lower limbs	1.085 (0.145)	1.115 (0.134)	1.197 (0.142)[a]	**0.016**
Total spine	0.894 (0.184)	0.957 (0.106)	0.996 (0.138)	0.055
WBLH	0.915 (0.118)	0.953 (0.094)	1.003 (0.115)[a]	**0.023**
BMAD-WBLH	0.091 (0.008)	0.085 (0.004)[a]	0.090 (0.007)[b]	**0.016**
Training parameters				
Weekly training (min/week)	--	1001 (196)	664 (369)[b]	**0.001**
Sporting experience (months)	--	56.2 (38.9)	39.9 (31.2)	0.139
RT (number athletes)	--	11	13	-

Significant differences among the groups (ANOVA) in bold. a= denotes significant difference compared to Control; b= denotes significant different compared to Swimmers; SD (standard deviation); PHV= peak height velocity; APHV= age of peak height velocity; RT= resistance training; BMAD= Bone mineral apparent density; WBLH=Whole body less head.

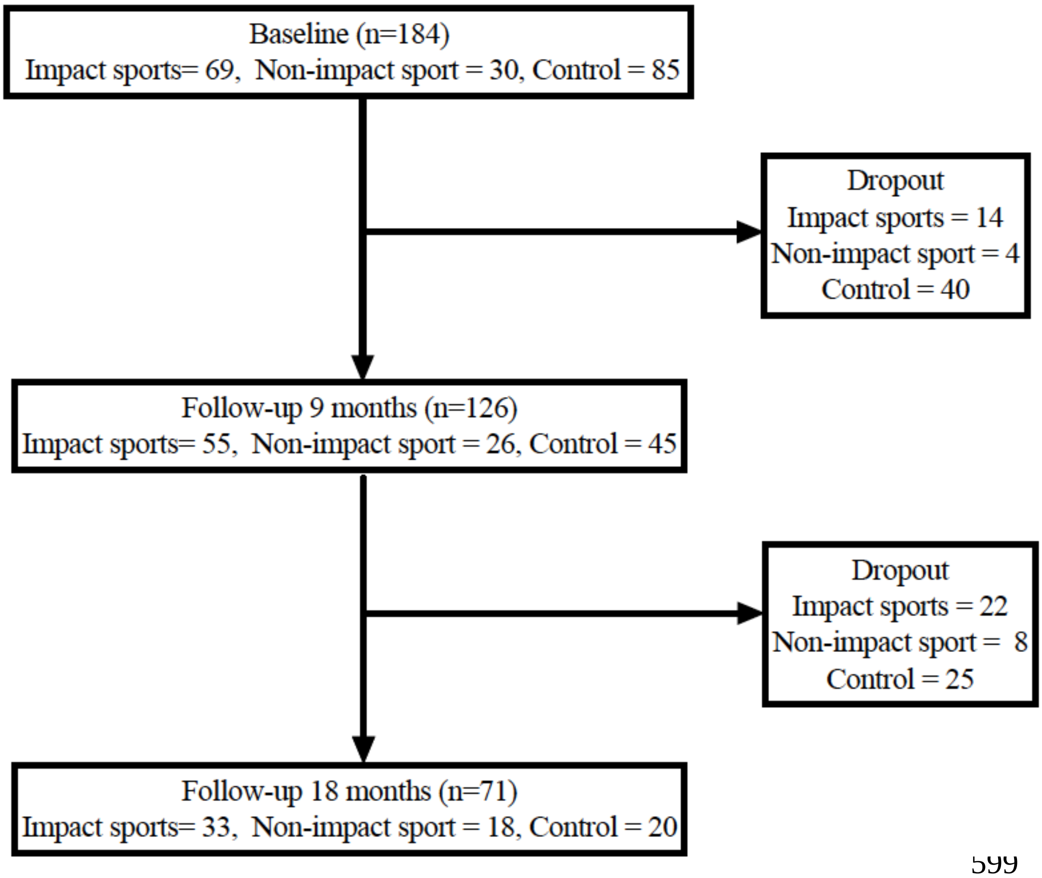

Figure 1. Flowchart of the study design

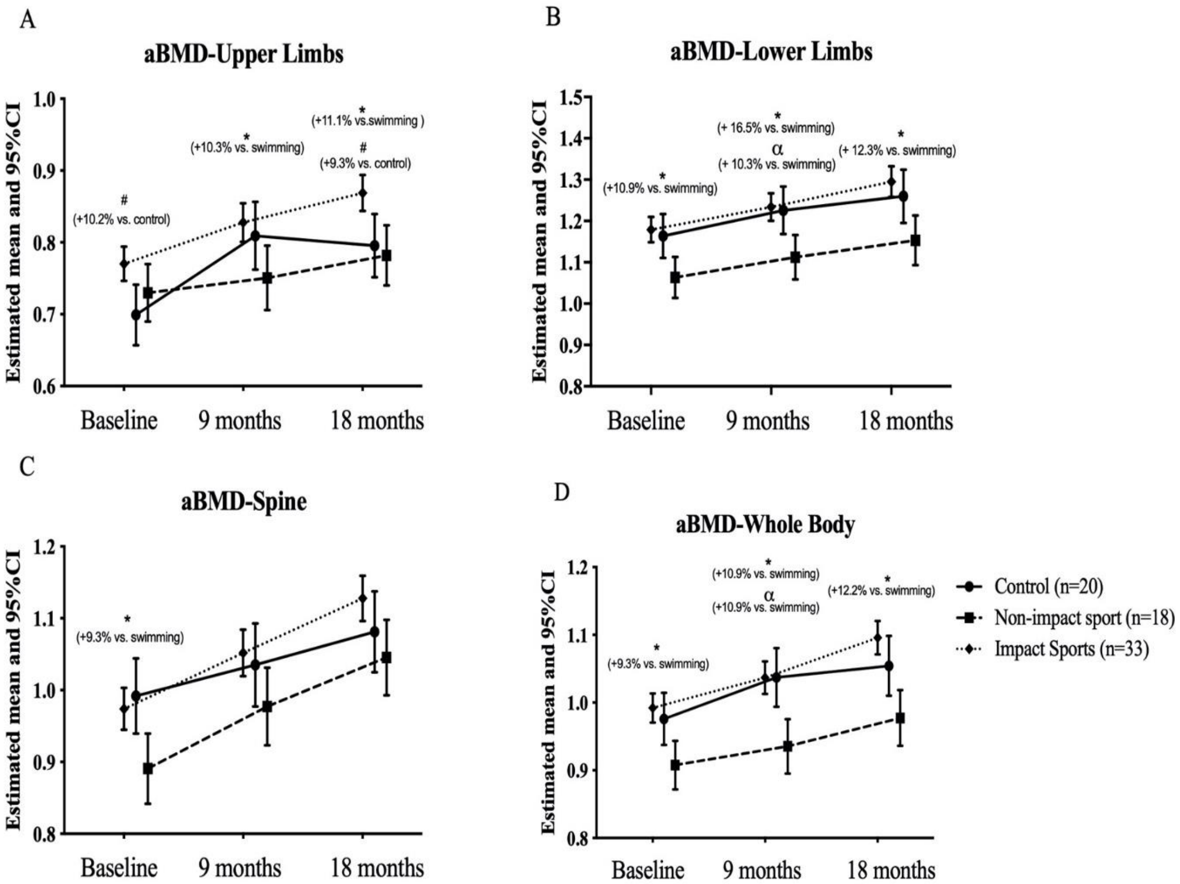

Figure 2. Areal bone mineral density (aBMD, g/cm²) status among adolescents of impact sports, non-impact sport and control group adjusted by age of PHV, lean soft tissue, volume of training, practice of resistance training, sporting experience, fat mass, height, vitamin D intake and sex. *significant difference between non-impact and impact sports; $^{\alpha}$significant difference between non-impact and control group; $^{\#}$significant difference between impact sports and control group. Values between brackets represent the percentage difference between the groups.

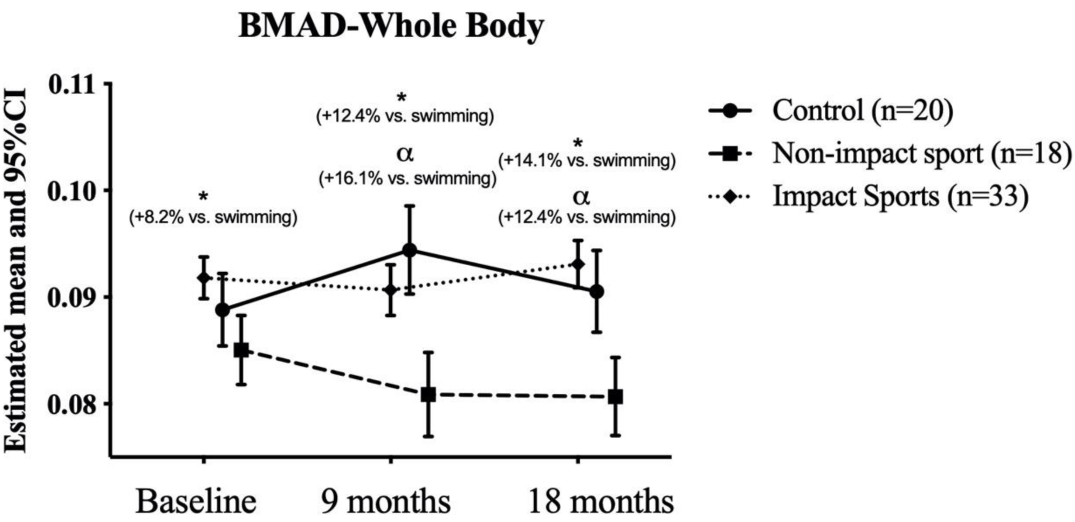

Figure 3. Bone mineral apparent density (,g/cm^3) status among adolescents of impact sports, non-impact sport and control group adjusted by age of PHV, lean soft tissue, volume of training, practice of resistance training, sporting experience, fat mass, height, vitamin D intake and sex. *significant difference between non-impact and impact sports; $^{\alpha}$ significant difference between non-impact and control group. Values between brackets represent the percentage difference between the groups.