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The effect of plyometric exercise on bone mineralisation and physical fitness in adolescents

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Abstract

Introduction. Plyometric exercise is the preferred type of exercise to promote bone health due to its role on providing high-impact loading of bone tissue. This study aimed to evaluate the effect of plyometric training on bone mineralisation and physical fitness between male and female adolescents.
Methods. This study was a parallel 2-arm trial with 1:1 randomisation to the plyometric or control group. This study was conducted at SMA Negeri 21 Makassar, Indonesia, which included 18 second year of high school students actively engaging in physical activity at least once a week. The plyometric training consisted of a warming-up period, plyometric session, and cooling-down period performed by participants in the plyometric group, three days/week for six months. The control group was informed to stay active during the study period. Bone mineralisation and physical fitness were assessed at baseline and after the 6-month intervention.
Results. A significantly higher improvement of VO_2 max was presented in the female plyometric group, compared to the control group (% improvement: 81.6 and 13.4 respectively; $p < 0.001$) over time. The plyometric group also experienced a significant increase (+4.9 cm) in body height over time, while the control group only demonstrated a slight increase (+1.4 cm). Significant increases in total dual femur BMD and trochanter BMC were observed in the male plyometric group.
Conclusions. The increases in BMD and BMC were only observed in male adolescents following plyometric training. Meanwhile, improvement in VO_2 max was more pronounced in female adolescents engaging with plyometric training.
Key words: adolescent, body height, bone density, exercise, oxygen consumption

Introduction

Osteoporosis is a major global public health concern with a quickly rising prevalence worldwide, affecting one in three women and one in five men over 50 years of age [1]. Globally, osteoporosis leads to more than 8.9 million fractures annually, resulting in an osteoporotic fracture every 3 s [2]. Moreover, it is considered a silent disease because most people do not become aware that they are at risk of fragility fractures until it occurs. It is also incurable as no current treatment is available to replenish the reduced bone mineral density (BMD) [3].

Several approaches have been identified to counteract the development of osteoporosis. However, timing plays an important role. It is known that the critical period for managing osteoporosis is adolescence, at which peak bone mass (PBM) can be optimised. Low BMD in adolescents is a risk factor for osteoporosis in later life [4]. A 10% increase in PBM can reduce the risk of osteoporotic fracture later in life by 50%. Several factors impact PBM, including genetic and lifestyle factors such as diet and physical activity. Thus, optimising lifestyle factors to increase PBM is encouraged as a strategy for osteoporosis prevention [5]. Adequate nutrition and exercise is the first-line strategy for the prevention of osteoporosis [6]. These actions are part of self-care practices, which are a series of behaviours to maintain and promote health [7]. Furthermore, it has been shown that weight-bearing physical activity/exercise is a more important factor than adequate calcium intake in achieving maximal PBM during youth [3].

Bone adaptation induced by exercise is mediated by cellular mechanotransduction [8]. Among all types of exercises, plyometric training is the preferred type of exercise to promote bone health. It is associated with high-ground reaction forces contributing to high-impact bone tissue loading [9]. A recent systematic review reported that jumping-based exercises during adolescence improve bone health parameters [10]. Research has revealed that an innovative and simple 8-month PJT (Bounce at the Bell; around 3 minutes per day) increased bone mass at the weight-bearing proximal femur in early puberty. In early pubertal girls, Mackelvie et al. [11–13] found that a 7-month jumping intervention (10 min, 3 times/week) was linked to increased bone at the femoral neck and lumbar spine (LS) and that these effects were maintained after 2 years. Plyometric training has been widely used in athletes, but it is still rarely applied in the adolescent population [14]. Because of the high variation of plyometric techniques, the optimal prescription of plyometrics on bone mineralisation in adolescents is not known yet. In prepubertal and early pubertal children, plyometric conducted three to five times per week over 5–24 months, is an efficient training approach for improving bone mass [15].

Aside from bone mineralisation, a previous systematic review suggested adjusting bone mineral changes with body height changes [10]. Another study conducted by Wainstein et al. [16] reported that moderate-to-high cardiorespiratory fitness levels might reduce the rate of bone loss. Therefore, apart from the direct effect of plyometric exercises on bone

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mineralisation, it is vital to identify its impact on other factors contributing to bone mineral changes, such as body height and cardiorespiratory fitness.

On the other side, emerging evidence reported that exercise responses are different between males and females. The current review demonstrated that the physiological response to exercise dosage is not the same in males and females [17]. This study aimed to evaluate the effect of plyometric training on bone mineralisation and physical fitness between male and female adolescents.

Subjects and methods

Participants and study design

This study was a 1:1 block-randomised, parallel, two-arm trial study conducted at SMA Negeri 21 Makassar, South Sulawesi, Indonesia. Participants were randomised to one of two study groups: the plyometric group or the control group. Group allocation was achieved using a computer-generated, 1:1 block randomisation scheme.

To minimise withdrawal potential due to the long study period, we chose second-grade students as participants. A screening test was conducted to select the eligible participants (the result of this screening is published elsewhere) [18]. The eligible subjects and their parents were informed about the study procedure and the risks and benefits. The consent forms and the flyers were provided for the parents. Inclusion criteria were (1) second-year high school students, (2) actively participating in physical exercise at least once per week, and (3) agreeing to be a participant in the study, confirmed by signed informed consent. Students having a disease that might impede their participation in plyometric exercise were excluded. Eligible participants were scheduled for baseline assessments. Physical fitness assessments were performed at SMA Negeri 21 Makassar. Bone mineralisation (BMD and BMC) evaluations were conducted at the Department of Radiology at the Hasanuddin University Hospital (HUH).

Intervention

Following baseline assessments, participants allocated to the plyometric group immediately began the 6-month program. The plyometric training consisted of a warming-up period (5 min), a plyometric session (10 min), and a cooling-down period (5 min). The plyometric exercises were performed three days/week for six months. The trained research assistants explained and demonstrated the plyometric exercises to the plyometric group to ensure correct techniques. Twenty-five techniques of plyometric exercises were used and varied in each session. The complexity of the training was increased progressively to optimise bone adaptation. Meanwhile, the control group participants were informed to stay active and maintain their physical activity during the study period.

Outcome measures

Bone mineralisation was the primary outcome measure. BMD and BMC were assessed using dual-energy x-ray absorptiometry (Lunar Corp., Model 8743, Madison, Wisconsin, USA) [19]. The physical fitness parameters measured in this study were body composition (body weight, body height, and body mass index) and cardiorespiratory endurance (VO_2 max). Body height was measured using a stadiometer (OneMed Stature Meter), and body weight was assessed using a digital scale (Idealife Home Innovations, Model IL-27I, China). Body mass index was calculated by the weight (kg) divided by the height squared (m). VO_2 max was measured using the Multi-Stage 20-m Shuttle Run Fitness Test (MSFT) or beep test [20]. Physical activity levels and socioeconomic statuses were also evaluated using The Physical Activity Questionnaire for Adolescents developed by Kowalski et al. [21] and the Family Affluence Scale (FAS), respectively [21, 22]. The detailed assessment procedure was published elsewhere.

Statistical analysis

A 2 (plyometric group vs. control) × 2 (male vs. females) × 2 (pre-test vs. post-test periods) ANOVA was used to examine training, gender, time, and interaction effects on BMD, BMC, maximal oxygen uptake, and anthropometric outcomes [23]. The effect size for partial eta squared was identified as > 0.01 (small), ≥ 0.06 (medium), and ≥ 0.14 (large). To determine statistical differences between the pre-test and post-study variables in each group, we performed a paired test. The effect size was calculated using Cohen's *d* with the following criteria: ≥ 0.20 (small), ≥ 0.50 (medium), and ≥ 0.80 (large) [24]. All statistical analyses were performed using SPSS Version 27.0 software (IBM Corporation), and the significance level was set at $p < 0.05$.

Results

Baseline characteristics of the study participants

A total of 17 participants, 9 in the plyometric group and 8 in the control group, completed this 6-month study (Figure 1). One participant in the plyometric group did not meet the post-test evaluation and was withdrawn from the study. Table 1 presents the baseline characteristics of study participants. No significant differences in characteristics were observed between the two groups ($p > 0.05$) at baseline. Initially, the plyometric training was to be conducted for eight months. However, due to the COVID-19 pandemic, this study was shortened to six months.

Effect of plyometric training on anthropometrics in female and male adolescents

Table 2 presents that male participants had a significant increase in body weight following 6 months of plyometric training ($p = 0.013$, $d = –1.921$). A significant increase in body weight was also demonstrated in the male control group ($p = 0.046$, $d = –1.642$). However, compared to the male control group, a larger effect size on body weight was reported in the male plyometric group (PG vs CG: $d = –1.921$ vs $d = –1.642$). On the other hand, no significant increases in body weights were observed in female participants in both the plyometric and control groups. In the plyometric group, both male and female participants presented significant increases in body height (male: $p < 0.001$, $d = –13.113$; female: $p = 0.001$, $d = –6.157$). Only male participants in the plyometric group showed a significantly lower BMI after 8 months of plyometric training ($p = 0.006$, $d = 2.435$).

Effect of plyometric training on physical fitness in female and male adolescents

Following 8 months of plyometric training, both male and female participants also demonstrated a significant improvement in VO_2 max ($p = 0.004$ and $p = 0.002$, respectively), with large effect sizes (male: $d = 2.64$; female: $d = 5.045$). In

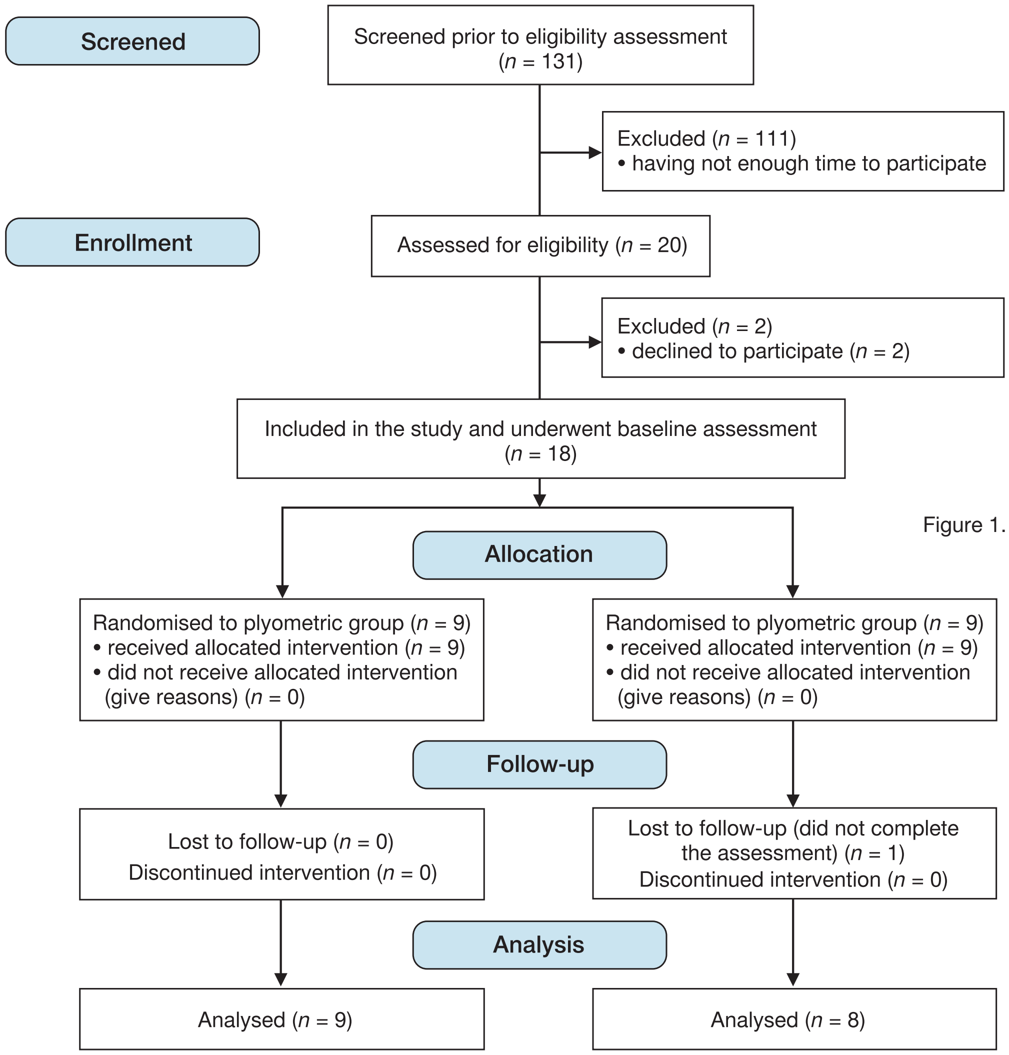

Figure 1. Flow chart of study participant

contrast, a significant improvement in VO_2 max was only reported in female participants in the control group ($p = 0.043$, $d = 1.70$). Male participants in the control group did not show significant improvement in VO_2 max ($p = 0.091$, $d = 1.23$). Repeated measures ANOVA yielded significant time × gender × intervention interaction effects for VO_2 max, $F(1,13) = 11.377$, $p = 0.005$, $\eta^2 = 0.467$ (Table 3). Specifically, male participants in both plyometric and control groups demonstrated similar significant increases in VO_2 max (% improvement: 29.3 and 25.85, respectively; $p = 0.808$) over six months (Table 2). On the other hand, a significantly greater improvement of VO_2 max was presented in the female plyometric group, compared to those in the control group (% improvement: 81.6 and 13.4, respectively; $p < 0.001$) over time. The effect size was larger for this comparison.

The significant time × intervention interaction effects were observed for VO_2 max ($F(1,13) = 27.736$, $p < 0.001$, $\eta^2 = 0.681$), body height ($F(1,13) = 20.889$, $p < 0.001$, $\eta^2 = 0.616$), and BMI ($F(1,13) = 7.165$, $p = 0.019$, $\eta^2 = 0.355$, Table 3). Specifically, participants in the plyometric group demonstrated significantly greater increases in VO_2 max as compared to those in the control group over the course of 6 months. The plyometric group experienced a significant increase (+4.9 cm) in body height over time, while the control group only demonstrated a slight increase (+1.4 cm). For BMI, a decrease over time (–0.67) was more pronounced in the plyometric group compared to the control group (–0.016). Meanwhile, no significant time x intervention interaction effect was observed for body weight, $F(1,13) = 1.233$, $p = 0.287$, $\eta^2 = 0.087$. The main significant effect of time was reported for body weight, $F(1,13) = 27.416$, $p < 0.001$, $\eta^2 = 0.678$. All participants displayed an increase in body weight over time.

Effect of plyometric training on bone mineralisation in female and male adolescents

A repeated-measures ANOVA using a within-subject factor of time (baseline, post-intervention) and between-subject factors of gender (male, female) and intervention (plyometric, control) revealed a significant main effect of time for total dual femur BMD ($F(1,13) = 5.493$, $p = 0.036$, $\eta^2 = 0.297$), trochanter BMD ($F(1,13) = 5.842$, $p = 0.031$, $\eta^2 = 0.31$), and shaft femur BMD ($F(1,13) = 5.376$, $p = 0.039$, $\eta^2 = 0.309$). Specifically, BMD in the total dual femur, trochanter site, and femoral shaft increased over time. Also, a marginally significant effect of time for neck BMD was observed ($F(1,13) = 4.376$, $p = 0.057$, $\eta^2 = 0.252$). All participants demonstrated a trend toward a higher BMD in the neck site over six months. Our study showed a marginal significant time × gender × intervention interaction effect for ward's triangle BMD ($F(1,13) = 3.802$, $p = 0.073$, $\eta^2 = 0.226$). Male participants in the plyometric group showed a trend toward greater improvement in ward's triangle BMD across time. Still, those in the control group demonstrated no differences across time. Surprisingly, a slight decrease in ward's triangle BMD was observed in female plyometric groups, compared to those in the control group.

Table 1. Baseline characteristics of study participants

Variable	Plyometric group (*n* = 9)	Control group (*n* = 8)	*p*-value
Age (years), mean ± *SD*	15.6 ± 0.5	15.9 ± 0.4	0.169
Gender, *n* (%)			
male	5 (55.6)	4 (50)	
female	4 (44.4)	4 (50)	
Physical activity, mean ± *SD*	2.87 ± 0.9	2.64 ± 0.5	0.547
Low level, *n* (%)	2 (22)		
Moderate level, *n* (%)	7 (78)	8 (100)	
Socioeconomic status, *n* (%)			
medium	6 (66.7)	6 (75)	
high	3 (33.3)	2 (25)	
Body weight (kg), mean ± *SD*	53.7 ± 7.9	58.9 ± 16.7	0.416
Body height (cm), mean ± *SD*	158.3 ± 5.0	161.4 ± 8.1	0.362
Body mass index (kg/m^2), mean ± *SD*	21.3 ± 2.3	22.6 ± 6.3	0.576
VO_2 max (ml/kg/min), mean ± *SD*	7.1 ± 2.4	5.3 ± 2.1	0.130
Bone mineral density (g/cm^2), mean ± *SD*			
total dual femur	0.948 ± 0.215	0.956 ± 0.194	0.937
neck femur	0.965 ± 0.212	0.959 ± 0.210	0.960
upper neck	0.878 ± 0.227	0.884 ± 0.235	0.962
lower neck	1.048 ± 0.199	1.032 ± 0.189	0.868
trochanter	0.734 ± 0.205	0.738 ± 0.165	0.962
wards	0.838 ± 0.279	0.849 ± 0.216	0.926
shaft femur	1.105 ± 0.242	1.122 ± 0.233	0.886
Bone mineral content (g), mean ± *SD*			
total dual femur	27.357 ± 7.026	26.652 ± 7.441	0.887
neck femur	4.376 ± 0.970	4.295 ± 1.085	0.872
upper neck	1.958 ± 0.487	1.947 ± 0.567	0.965
lower neck	2.417 ± 0.493	2.345 ± 0.530	0.774
trochanter	7.873 ± 2.841	7.512 ± 2.680	0.792
wards	1.921 ± 0.646	1.907 ± 0.633	0.966
shaft femur	15.093 ± 3.313	14.846 ± 3.741	0.887

Table 2. Effect of plyometric training on physical fitness

Variable	Gender	Plyometric group (*n* = 9)				Control group (*n* = 8)				Between-group comparison, % change		
		pre (mean ± *SD*)	post (mean ± *SD*)	*p*	*d*	pre (mean ± *SD*)	post (mean ± *SD*)	*p*	*d*	plyometric group (mean ± *SD*)	control group (mean ± *SD*)	*p*
Body weight (kg)	male	56.0 ± 9.6	57.6 ± 9.6	0.013	–1.921	56.5 ± 14.0	57.6 ± 14.5	0.046	–1.642	2.79 ± 1.36	1.90 ± 1.02	0.316
	female	50.9 ± 4.78	52.5 ± 4.68	0.141	–0.994	61.5 ± 21.05	62.4 ± 21.66	0.095	–1.203	3.2 ± 3.14	1.3 ± 0.90	0.305
Body height (m)	male	161.6 ± 4.1	167.4 ± 4.2	0.000	–13.113	165.1 ± 9.1	167.1 ± 8.3	0.285	–0.65	3.6 ± 0.3	1.3 ± 1.9	0.031
	female	154.4 ± 2.52	158.4 ± 2.01	0.001	–6.157	157.8 ± 6.13	158.6 ± 5.98	0.099	–1.180	2.6 ± 0.40	0.5 ± 0.44	< 0.001
Body mass index (kg/m^2)	male	21.4 ± 3.0	20.5 ± 2.9	0.006	2.435	20.9 ± 5.6	20.7 ± 5.5	0.712	0.203	–4.23 ± 1.6	–0.55 ± 2.98	0.048
	female	21.3 ± 1.47	20.9 ± 1.44	0.238	0.734	24.4 ± 7.34	24.5 ± 7.51	0.482	–0.40	–2.0 ± 2.72	0.3 ± 0.94	0.158
VO_2 max (ml/kg/min)	male	8.6 ± 1.6	10.9 ± 1.0	0.004	–2.64	6.85 ± 2.2	8.35 ± 1.83	0.091	–1.23	29.3 ± 17.9	25.85 ± 23.74	0.808
	female	5.4 ± 2.18	9.5 ± 2.90	0.002	–5.045	3.9 ± 0.32	4.4 ± 0.22	0.043	–1.70	81.6 ± 17.48	13.4 ± 8.70	< 0.001

Table 3. Results of factorial analysis of variance

Variable	Time		Group		Gender		Time × group		Time × gender		Group × gender		Time × group × gender	
	F (*p*)	η^2	*F* (*p*)	η^2	*F* (*p*)	η^2	*F* (*p*)	η^2	*F* (*p*)	η^2	*F* (*p*)	η^2	*F* (*p*)	η^2
Body weight (kg)	27.416 (< 0.001)	0.678	0.62 (0.445)	0.046	0.000 (0.983)	0.000	1.233 (0.287)	0.087	0.037 (0.85)	0.003	0.561 (0.467)	0.041	0.07 (0.795)	0.005
Body height (cm)	68.045 (< 0.001)	0.840	0.379 (0.549)	0.028	8.287 (0.013)	0.389	20.889 (< 0.001)	0.616	3.866 (0.071)	0.229	0.002 (0.963)	0.000	0.138 (0.717)	0.010
BMI (kg/m^2)	7.896 (0.015)	0.378	0.48 (0.5)	0.036	0.674 (0.427)	0.049	7.165 (0.019)	0.355	2.12 (0.169)	0.14	0.567 (0.465)	0.041	0.195 (0.666)	0.015
VO_2 max	100 (< 0.001)	0.885	10.903 (0.006)	0.456	12.130 (0.004)	0.483	27.736 (< 0.001)	0.681	1.012 (0.333)	0.072	0.502 (0.491)	0.037	11.377 (0.005)	0.467
Bone mineral density														
total dual femur	5.493 (0.036)	0.297	0.002 (0.966)	0.000	0.202 (0.660)	0.015	0.008 (.929)	0.001	1.762 (0.207)	0.119	0.008 (0.930)	0.001	1.598 (0.228)	0.109
neck femur	4.376 (0.057)	0.252	0.021 (0.886)	0.002	0.126 (0.728)	0.01	0.493 (0.495)	0.037	0.279 (0.606)	0.021	0.169 (0.687)	0.013	0.097 (0.761)	0.007
upper neck	1.526 (0.239)	0.105	0.001 (0.974)	0.000	0.144 (0.710)	0.011	0.132 (0.722)	0.010	1.489 (0.244)	0.103	0.224 (0.644)	0.017	0.428 (0.524)	0.032
lower neck	2.188 (0.163)	0.144	0.029 (0.869)	0.002	0.054 (0.821)	0.004	0.072 (0.793)	0.005	1.133 (0.306)	0.08	0.064 (0.804)	0.005	0.009 (0.924)	0.001
trochanter	5.842 (0.031)	0.31	0.000 (0.987)	0.000	0.285 (0.603)	0.021	0.008 (0.929)	0.001	0.039 (0.847)	0.003	0.000 (0.983)	0.000	1.125 (0.308)	0.08
wards	0.481 (0.50)	0.036	0.000 (1.00)	0.000	0.432 (0.523)	0.032	0.130 (0.724)	0.010	1.378 (0.262)	0.096	0.054 (0.820)	0.004	3.802 (0.073)	0.226
shaft femur	5.376 (0.039)	0.309	0.933 (0.353)	0.072	0.234 (0.637)	0.019	0.346 (0.567)	0.028	0.903 (0.361)	0.07	0.650 (0.436)	0.051	0.328 (0.577)	0.027
Bone mineral content (g)														
total dual femur	4.62 (0.053)	0.278	0.298 (0.59)	0.024	1.35 (0.27)	0.101	0.085 (0.77)	0.007	0.46 (0.51)	0.037	0.96 (0.35)	0.074	0.00 (0.99)	0.00
neck femur	0.299 (0.594)	0.022	0.022 (0.885)	0.002	0.072 (0.792)	0.006	0.014 (0.907)	0.001	2.051 (0.176)	0.136	0.013 (0.912)	0.001	0.115 (0.740)	0.009
upper neck	0.095 (0.763)	0.007	0.005 (0.946)	0.000	0.021 (0.886)	0.002	0.142 (0.713)	0.011	3.803 (0.073)	0.226	0.001 (0.974)	0.000	0.011 (0.920)	0.001
lower neck	0.52 (0.484)	0.038	0.054 (0.819)	0.004	0.157 (0.698)	0.012	0.016 (0.901)	0.001	0.828 (0.379)	0.06	0.069 (0.798)	0.005	0.358 (0.56)	0.027
trochanter	7.71 (0.016)	0.372	0.087 (0.772)	0.007	0.11 (0.745)	0.008	1.619 (0.225)	0.111	0.714 (0.413)	0.052	0.035 (0.855)	0.003	0.118 (0.773)	0.009
wards	0.006 (0.941)	0.000	0.002 (0.965)	0.000	0.054 (0.820)	0.004	0.09 (0.769)	0.007	0.949 (0.348)	0.068	0.239 (0.633)	0.018	0.808 (0.385)	0.059
shaft femur	3.319 (0.093)	0.217	0.356 (0.562)	0.029	1.369 (0.265)	0.102	0.037 (0.851)	0.003	0.058 (0.813)	0.005	0.887 (0.365)	0.069	0.266 (0.615)	0.022

However, no other significant main or interaction effects were found. On the other hand, a significant increase in total dual femur BMD was observed in male participants engaged in plyometric training ($p = 0.019$; $d = 1.739$). Also, this study found a marginally significant increase in femoral shaft BMD in the male plyometric group ($p = 0.054$; $d = 1.204$, Tables 4 and 5).

There was a significant increase in the male plyometric group's trochanter bone mineral content ($p = 0.015$; $d = 1.814$). An ANOVA with repeated measures revealed a significant main effect of time for trochanter BMC ($F(1,13) = 7.71$, $p = 0.016$, $\eta^2 = 0.372$). However, we also found a marginally significant effect of time on total dual femur BMC ($F(1,13) = 4.62$, $p = 0.053$, $\eta^2 = 0.278$) and femoral shaft BMC ($F(1,13) = 3.319$, $p = 0.093$, $\eta^2 = 0.217$). All participants demonstrated a trend toward a higher BMC in the total dual femur and femoral shaft over the six months. A marginally significant time x gender interaction effect was also observed for upper neck BMC ($F(1,13) = 3.803$, $p = 0.073$, $\eta^2 = 0.226$). While male participants demonstrated a higher BMC in the upper neck site, a slight decrease in upper neck BMC was observed in female participants. Other than that, no significant gender and intervention and interaction effects were observed.

Discussion

Effect of plyometric training on anthropometrics in female and male adolescents

The present study revealed that plyometric training could result in an increased body height over six months. Pienaar and Coetzee [25] showed that plyometric exercises combined with rugby conditioning can improve body height among rugby players. Our study also indicated that the increase in body weight over the study's course was attributed to growth and

Table 4. Effect of plyometric training on bone mineral density

Bone mineral density (g/cm²)	Gender	Plyometric group (n = 9)				Control group (n = 8)				Between-group comparison, % change		
		pre (mean ± *SD*)	post (mean ± *SD*)	*p*	*d*	pre (mean ± *SD*)	post (mean ± *SD*)	*p*	*d*	plyometric group (mean ± *SD*)	control group (mean ± *SD*)	*p*
Total dual femur	male	0.92 ± 0.91	0.95 ± 0.10	0.019	1.739	0.94 ± 0.19	0.95 ± 0.18	0.434	0.449	3.10 ± 1.63	1.82 ± 3.36	0.474
	female	0.98 ± 0.33	0.98 ± 0.31	0.894	0.075	0.98 ± 0.23	0.99 ± 0.23	0.224	0.763	0.25 ± 3.09	1.37 ± 1.99	0.567
Neck femur	male	0.93 ± 0.09	0.95 ± 0.10	0.062	1.143	0.96 ± 0.24	0.98 ± 0.21	0.328	0.580	2.74 ± 2.27	2.73 ± 4.77	0.997
	female	1.01 ± 0.32	1.03 ± 0.34	0.444	0.446	0.96 ± 0.22	0.97 ± 0.22	0.794	0.139	2.10 ± 4.81	0.28 ± 3.87	0.577
Upper neck	male	0.83 ± 0.09	0.86 ± 0.09	0.065	1.129	0.89 ± 0.27	0.9 ± 0.24	0.576	0.313	3.51 ± 3.06	2.49 ± 6.57	0.764
	female	0.94 ± 0.34	0.94 ± 0.33	0.918	0.054	0.88 ± 0.24	0.88 ± 0.24	0.885	0.078	0.21 ± 4.75	0.19 ± 3.77	0.995
Lower neck	male	1.02 ± 0.09	1.05 ± 0.11	0.174	0.735	1.03 ± 0.21	1.05 ± 0.18	0.306	0.616	2.15 ± 2.93	3.18 ± 4.52	0.690
	female	1.08 ± 0.3	1.08 ± 0.27	0.985	0.01	1.04 ± 0.19	1.04 ± 0.21	0.703	0.214	0.75 ± 5.32	0.47 ± 4.03	0.937
Trochanter	male	0.71 ± 0.11	0.73 ± 0.11	0.103	0.949	0.72 ± 0.16	0.73 ± 0.15	0.881	0.300	3.09 ± 3.08	1.74 ± 4.10	0.590
	female	0.77 ± 0.31	0.78 ± 0.31	0.628	0.269	0.76 ± 0.19	0.78 ± 0.19	0.209	1.211	0.97 ± 3.69	3.1 ± 2.73	0.398
Wards	male	0.78 ± 0.14	0.82 ± 0.16	0.085	1.014	0.83 ± 0.24	0.82 ± 0.21	0.59	0.081	5.5 ± 4.87	0.90 ± 7.84	0.317
	female	0.92 ± 0.4	0.89 ± 0.37	0.41	0.490	0.87 ± 0.22	0.88 ± 0.22	0.097	0.804	–1.42 ± 4.25	1.38 ± 1.72	0.269
Shaft	male	1.08 ± 0.10	1.11 ± 0.12	0.054	1.204	1.11 ± 0.21	1.12 ± 0.21	0.482	0.405	3.24 ± 2.55	1.66 ± 3.72	0.471
	female	0.96 ± 0.15	0.97 ± 0.13	0.574	0.385	1.14 ± 0.29	1.15 ± 0.29	0.4	0.479	1.47 ± 3.03	0.91 ± 1.93	0.774

Table 5. Effect of plyometric training on bone mineral content

Bone mineral content (g)	Gender	Plyometric group (n = 9)				Control group (n = 8)				Between-group comparison, % change		
		pre (mean ± *SD*)	post (mean ± *SD*)	*p*	*d*	pre (mean ± *SD*)	post (mean ± *SD*)	*p*	*d*	plyometric group (mean ± *SD*)	control group (mean ± *SD*)	*p*
Total dual femur	male	28.18 ± 4.45	29.0 ± 4.77	0.161	0.769	26.86 ± 6.68	27.53 ± 6.26	0.300	0.625	2.92 ± 3.63	2.89 ± 3.67	0.993
	female	21.45 ± 3.39	21.92 ± 2.52	0.516	0.451	26.45 ± 9.2	26.76 ± 9.32	0.565	0.322	2.63 ± 4.83	1.34 ± 4.56	0.734
Neck femur	male	4.45 ± 0.7	0.51 ± 0.77	0.340	0.484	4.3 ± 1.05	4.39 ± 0.87	0.448	0.435	1.48 ± 3.24	2.95 ± 5.26	0.619
	female	4.29 ± 1.36	4.27 ± 1.27	0.866	0.092	4.29 ± 1.28	4.24 ± 1.33	0.414	0.473	0.15 ± 4.91	–1.71 ± 3.08	0.546
Upper neck	male	1.96 ± 0.32	2.01 ± 0.35	0.204	0.677	1.96 ± 0.56	1.99 ± 0.49	0.502	0.381	2.5 ± 3.79	2.70 ± 6.23	0.954
	female	1.96 ± 0.71	1.94 ± 0.70	0.595	0.297	1.94 ± 0.66	1.91 ± 0.65	0.271	0.674	–1.09 ± 4.53	–1.98 ± 2.69	0.748
Lower neck	male	2.5 ± 0.39	2.51 ± 0.43	0.610	0.247	2.34 ± 0.51	2.41 ± 0.38	0.437	0.448	0.81 ± 3.85	3.52 ± 5.64	0.420
	female	2.33 ± 0.66	2.34 ± 0.58	0.908	0.063	2.35 ± 0.63	2.33 ± 0.69	0.655	0.247	1.11 ± 5.58	–1.28 ± 3.37	0.491
Trochanter	male	8.17 ± 2.05	8.61 ± 2.23	0.015*	1.814	7.60 ± 2.26	7.78 ± 2.1	0.443	0.441	5.28 ± 2.05	2.92 ± 4.57	0.331
	female	7.51 ± 3.95	7.75 ± 4.21	0.247	0.717	7.43 ± 3.41	7.51 ± 3.39	0.716	0.200	2.68 ± 3.82	2.09 ± 9.26	0.909
Wards	male	1.99 ± 0.58	2.07 ± 0.56	0.358	0.464	1.873 ± 0.51	1.86 ± 0.33	0.922	0.053	4.30 ± 7.53	1.29 ± 9.17	0.604
	female	1.83 ± 0.8	1.77 ± 0.74	0.420	0.467	1.95 ± 0.82	1.94 ± 0.83	0.527	0.357	–2.24 ± 7.05	–0.99 ± 2.50	0.750
Shaft	male	15.57 ± 1.80	15.87 ± 1.97	0.452	0.372	14.96 ± 3.45	15.38 ± 3.40	0.254	0.703	2.01 ± 5.07	2.94 ± 3.63	0.767
	female	12.15 ± 1.75	12.55 ± 1.09	0.409	0.599	14.73 ± 4.55	14.88 ± 4.84	0.643	0.257	3.85 ± 5.84	0.69 ± 4.05	0.767

* statistically significant $p < 0.05$

developmental changes. While no effect of plyometric training on body weight was observed, BMI was significantly lower following plyometric training. A study by Racil et al. [26] shows that plyometric exercise combined with high-intensity interval training can improve the body mass index among young obese women.

Effect of plyometric training on physical fitness in female and male adolescents

Both the control and plyometric groups demonstrated significant improvements in VO_2 max. Compared to the female plyometric group, the male plyometric group demonstrated a lower effect size (ES: 2.64 vs. 5.045). Nonetheless, the male and female plyometric groups showed a significant improvement in VO_2 max following 8 months of training. It has been shown that there are gender differences in exercise responses. Recent research revealed that peripheral and pulmonary oxygen extraction dynamics during exercise were higher in women than in men. Other than that, the higher composition of slow-twitch muscle fibres in women might have accounted for those differences [27]. A previous study indicated that haemoglobin concentrations were a significant factor contributing to sex differences in maximal oxygen uptake. However, other factors, such as the oxygen transport system and musculature, might significantly affect maximal oxygen uptake [28].

Effect of plyometric training on bone mineralisation in female and male adolescents

Bone modelling is stimulated by mechanical loading from physical activity such as plyometric exercises to create a stronger skeleton in the developmental phase of adolescence [29]. Surprisingly, in our study, the effect of plyometric training was not observed for BMD. This phenomenon might result from a limited intervention period of training. Initially, the plyometric training would be conducted for eight months. However, due to the COVID-19 pandemic, this study was only run for six months. Another study that showed jump-based training for 12 weeks also reported no significant increases in BMD [24]. Our study only found the main effect of time for the total dual femur, trochanter, and femoral shaft BMD. It can be assumed that the growth and developmental changes accounted for our findings.

The results of this study are supported by previous studies which reported that children and adolescents (8–15 years) participating in high physical activity have 8–10% more BMC in the hip during adulthood (23–30 years) than children or adolescents who lacked physical activity [30, 31]. Weaver et al. [29, 30] argued that physical activity creates mechanical loads on the bone and muscle forces, causing strain on other bone parts. These strains can stimulate mechanosensitive cells, such as osteocytes, present in bone and provide signals to activate osteoblasts and osteoclasts. Changes in physical activity and other mechanical load factors, such as body weight, are the initial bone adaptation signalling processes. Bone adaptation can trigger an osteogenic response in the bone because it experiences a magnitude of stretch that exceeds the standard threshold [29, 31].

This study revealed that the significant improvement of BMD and BMC was more pronounced in male adolescents than female adolescents. This finding might result from a higher level of receptor activator of NF-kB ligand (RANKL) and osteoprotegerin (OPG) expressed in males compared to females [29]. Those factors are enhanced by plyometric exercise, responsible for suppressing osteoclast genesis and bone remodelling and released by osteocytes, osteoblasts, and MSCs. One of the previous studies evaluated the osteokines responses in rest and plyometric exercises in boys and girls ten years old [29]. It showed that boys had a higher level of RANKL in pre-exercise measurements compared to girls, and through exercise, the expression of RANKL remained lower in girls until exercise was performed for 24 hours. Furthermore, the amount of OPG is enhanced by applying exercise, especially in 5-minute and 1-hour exercises for boys and only at 24 hours of exercise for girls.

Limitations

This study has several limitations. It has a small sample size, and the duration of the intervention was less than eight months. However, this study is the first study of plyometric training conducted on students in Indonesia. This study's findings may inform the implementation of plyometric training to improve physical activity levels among students in Indonesia.

Conclusions

Our findings show that 6 months of plyometric training increased body height while decreasing BMI. However, improvement in VO_2 max was more pronounced in female adolescents engaging in plyometric training. Meanwhile, the increases in BMD and BMC were only observed in male adolescents following plyometric training. Our study suggested that the effect of exercise can be affected by gender. Therefore, further research is needed to construct different dosages of plyometric exercises for male and female adolescents.

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Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Ethical Committee of Medical Faculty, Hasanuddin University (approval No.: 574/UN4.6.4.5.31/PP36/2019).

Informed consent

All participants provided written informed consent to confirm their participation in this study. Participation was voluntary, and the participants were allowed to stop participating anytime during the study. Any adverse effects experienced by the participants were checked on in a timely manner.

Disclosure statement

No author had any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

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