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Bone mineral density in male weight-classified athletes is higher than that in male endurance-athletes and non-athletes

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Running Head: BMD in weight-classified athletes

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Abstract

Background: Weight-bearing physical activity and intense mechanical stimuli affect the bone through the endocrine system; hence, bone-loading sports affect bone mineral density. We hypothesized that weight-classified athletes, such as those practicing wrestling and judo, have relatively high bone mineral density because these activities have a higher impact on the entire body during daily training compared to low- or non-impact activities. We aimed to investigate the bone mineral density of weight-classified athletes (participating in wrestling and judo) to compare the parameters with those of endurance-athletes and non-athletes.

Methods: Thirty-three college athletes (aged 18-22 years) were divided into three groups, wrestlers, judoka, and endurance-athletes, according to their sports history. Eight non-athletes participated as controls. Bone mineral density was determined by whole-body dual-energy X-ray absorptiometry.

Results: Mean whole-body bone mineral density of wrestlers and judoka was higher than that of endurance-athletes and non-athletes ($P<0.01$). The bone mineral density of athletes competing in wrestling and judo was higher than that of non-athletes when adjusted for body mass.

Conclusions: The present study demonstrated that weight-classified athletes have

significantly higher bone mineral density compared to endurance- and non-athletes, despite rapid weight loss before competitions.

Keywords: Weight-cycling, Dual-energy X-ray absorptiometry, Athletes

Abbreviations:

BMD, bone mineral density

DXA, dual-energy x-ray absorptiometry

SD, standard deviation

ANOVA, one-way analysis of variance

ANCOVA, analysis of covariance

INTRODUCTION

It is important to maintain or enhance bone health and therefore minimize bone injury in weight-classified athletes who participate in direct contact sports such as wrestling, judo, and boxing. Energy, vitamin D, and calcium intake all play a role in bone health [1–3]. Thus, there are concerns that insufficient food intake in athletes could result in low energy availability and nutrient deficiency, which could lead to low bone mineral density (BMD) [4]. Energy availability is defined as energy intake (kcal) minus exercise energy expenditure (kcal) divided by kilograms of fat-free mass [5]. Weight-classified athletes are likely to experience low energy availability because they usually lose weight rapidly before a competition, maintaining high-volume training activity with severe energy restriction [6]. Since these athletes lose weight several times a year for tournaments, it is expected that their BMD would be negatively affected. This means these athletes have to experience some episodes of low energy availability over a year, otherwise the weight loss would be short-term. Furthermore, there is a risk of vitamin D insufficiency or deficiency, which may also impact bone health, and is of particular concern since most of the weight-classified sports are practiced indoors [7].

It is widely known that weight-bearing physical activity benefits the bone. Tenforde et al. [8] showed that the BMD z-score of athletes in non-weight-bearing sports, such swimming and cycling, were low compared to that of other athletes. Recent research has confirmed these findings, where a high prevalence of low BMD (z-score < -1.0) was found in competitive cyclists [9]. Hence, it is possible that repeated bone impact may be associated with BMD. For example, cross-country running and other high energy-expenditure sports involve repetitive, lower-impact forces that may not result in high bone strength compared to that in team sports such as soccer [10]. It has already been shown that jumping, which creates higher bone impact than running, results in stiffer, more fracture-resistant bones [11]. Consequently, sports that involve high bone impact may result in higher BMD in athletes if high impact activity does indeed increase BMD. In wrestling and judo, athletes experience high impact on the whole body during daily training because combat sports involve direct contact with competitors. Therefore, it is possible that the BMD of weight-classified athletes, such as wrestlers and judoka, are significantly higher than that of athletes in other sports despite weight-cycling and indoor training. A recent study reported that low BMD in male athletes in different types of sport activity was associated with bone stress injuries [12]. However, there have been a few studies that have focused on weight-classified athletes subjected to severe energy restriction and weight loss during a competitive season several times in a year. Their BMD should be monitored because their bodies are directly exposed to punches or tackles.

In this study, we aimed to investigate the BMD of weight-classified athletes and to compare it with that of endurance-athletes and non-athletes. We hypothesized that the BMD of weight-classified athletes would be higher than that of endurance-athletes and non-athletes.

METHODS

This study was a cross-sectional trial sample of young Japanese men. In total, 41 healthy adults aged ≥18 years were enrolled through a prospective open recruitment between universities in the Kanto region of Japan (age 18-24 years). In the present study, individuals participating in 4 or more sessions of high-volume training per week as ascertained from weekly training records were defined as athletes [n=33], as in our previous study (**Table 1**) [13]. The number of training days for athletes was 5.9±1.0 (range 4–7) days per week, which was obtained within 7 days of dual-energy x-ray absorptiometry (DXA) measurement; whereas, the non-athletes were recruited and confirmed as none or one exercise per week [n=8] at screening. The athletes were further divided into three groups, “wrestlers” [n=11], “judoka” [n=9], and “endurance-athletes” [n=13] according to each individual’s sporting background. Weight-classified athletes, who participated in wrestling or judo, usually conducted weight-cycling before competition at least 3 times per year and had experienced loss of >5% of their body mass before a major competition. The athletes participated in these events within or after the season. The endurance-athletes were 10 triathletes, 2 endurance cyclists, and one orienteer. We confirm that none of the participants were taking any medications, and none had thyroid or heart disease. All participants provided written informed consent. The study protocol was approved by the ethics committee of Japan Institute of Sports Sciences (approval no. 036 and 050).

Measurements

The participants refrained from hard training and consuming alcohol or stimulant beverages for at least 24 h prior to the measurements. They were instructed to abstain from consuming all food and beverages after 23:00 of the day preceding the evaluation. The participants presented to the laboratory at 06:30 and voided urine. The participants' height was measured within the nearest 0.1 cm with a stadiometer and their body mass was measured to the nearest 0.01 kg using an electronic scale (A&D Co. Ltd., Tokyo, Japan). BMD and body composition were determined using DXA (Discovery A, Hologic, Waltham, MA, USA) whole-body scans. The same technician positioned the participants, performed all scans, and executed the analysis according to the operator's manual using the standard analysis protocol. Participants wore a swimsuit, were barefoot, and positioned on the scanner table with arms out to the side, hands flat on the table, and feet in the plantar-flexed position for 5–10 min according to the manufacturer's guidelines and our previous studies [6,14]. For data analysis of the whole body, the trunk, arm, and leg measurements were considered [15]. Body composition is presented as fat mass and fat-free mass including bone mineral content.

Statistical analysis

Results are presented as mean ± standard deviation (SD). The differences between-groups were examined using one-way analysis of variance (ANOVA). Pearson correlation coefficients were used as measures of correlation between whole-body BMD and body mass, age, and height. To eliminate confounding effects, analysis of covariance (ANCOVA) was used to analyze between-group differences whole-body BMD adjusting with body mass. When a significant difference was detected, a multiple comparison test was performed using Tukey's post-hoc test for the least significant difference between the groups. All analyses were performed using IBM SPSS 23.0 for Mac (IBM, New York, NY). For all the analyses, $P<0.05$ was used to denote statistical significance.

RESULTS

In total, 41 participants (33 athletes and 8 non-athletes) completed the DXA measurements for BMD. The characteristics of the participants included in the analysis are summarized in **Table 1**. There were significant differences in body mass, BMI, percent of fat, fat mass, and fat-free mass but no differences in age or height between the groups. There was a significant, moderately positive correlation between whole-body BMD and body mass (r = 0.439, P=0.004), but whole-body BMD was not significantly correlated with age (r = -0.230, P = 0.204) or height (r = -0.061, P = 0.703).

The mean whole-body BMD of athletes in the weight-classified sports, i.e., wrestlers (1.366±0.060 g/cm^2; 95% CI: 1.325, 1.466) and judoka (1.282±0.066 g/cm^2; 95% CI: 1.231, 1.333) was higher than those of endurance-athletes (1.175±0.081 g/cm^2; 95% CI: 1.125, 1.224) and non-athletes (1.161±0.092 g/cm^2; 95% CI: 1.084, 1.238) (P<0.01, see **Table 1**). The whole-body BMD of wrestlers (1.360±0.052 g/cm^2; 95% CI: 1.325, 1.395) and judoka (1.264±0.074 g/cm^2; 95% CI: 1.207, 1.321) remained higher than that of non-athletes (1.164±0.092 g/cm^2; 95% CI: 1.087, 1.241), when adjusted for body mass (**Figure 1**). The difference between judoka and endurance-athletes disappeared when adjusted for body mass (**Figure 1**). The distribution of whole-body

BMD z-score value for each participant separated by group is displayed in **Figure 2**. The average whole-body BMD z-score values for each group were: wrestlers, 3.6±1.0; judoka, 2.2±1.1; endurance-athletes, 0.5±1.3; and non-athletes, 0.3±1.5. Low whole-body BMD (z-score < -1.0) was observed in endurance- and non-athletes. High whole-body BMD (z-score > 1.0) was found in wrestlers and judoka.

The segmental BMD values, which are separated by trunk, arms, and legs, are shown in **Table 2**. The segmental BMD of wrestlers were higher than those of endurance- and non-athlete groups in the trunk, arms, and legs (P<0.01). These remained higher when adjusted for body mass (P<0.01). Moreover, BMD values for judoka were higher than those in the endurance- and non-athlete groups in the trunk and arms, but the difference in trunk BMD disappeared when compared to that of non-athletes after adjusting for body weight.

DISCUSSION

Results from the present study show that the BMD of wrestlers and judoka are higher than that of endurance- and non-athletes. Wrestlers had the highest BMD when adjusted for body weight. This aligns with previous findings of weight-classified athletes participating in wrestling and judo who had very high z-scores compared to that of the general population of Asian youth [16]. This is the first study to describe a higher BMD for weight-classified athletes who regularly participate in whole-body high-impact activity and rapid weight-cycling several times a year.

It is known that athletes who receive whole-body mechanical stimuli have higher BMD. According to the literature, the BMD of the average Japanese male is 1.10 g/cm^2 [17]. Previous studies have reported the BMD reference for swimmers (1.167 g/cm^2) and triathletes (1.153 g/cm^2), who participate in sports with less bone mechanical stimuli than combat sports, which are lower compared to athletes participating in sports with more physical contact such as basketball (1.299 g/cm^2) and handball (1.364 g/cm^2) [18]. Another epidemiological study reported that BMD is higher in runners compared to cyclists [19] and this result may account for significantly higher femoral BMD in recreational male runners [20]. Participants in endurance sports in this study comprised triathletes (1.188±0.083 g/cm^2), two cyclists (1.116 and 1.069

g/cm^2), and one orienteer (1.207 g/cm^2) in this study. Indeed, the type of sport may involve different mechanical stimuli and BMD as indicated by the prior studies described above. We speculated that the BMD was greater in wrestling and judo than in these endurance sports, although our study could not directly compare different endurance sports. The BMD for wrestlers in the present study was similar to the National College Athletic Association average for wrestlers (1.459 g/cm^2) [21], and was higher than for previously described sports. This is in line with a recent study showing that athletes participating in high-impact sports have significantly higher BMD than those in low-impact sports and a control group [22]. In a previous study describing the physiological results of bone impact, a relationship was shown between bone loading activity and the release of bone alkaline phosphatase and osteocalcin secreted from osteoblasts [23]. Since osteocalcin is secreted only from osteoblasts and is involved in bone mineralization and calcium ion concentration homeostasis, the repetitive impact of wrestling and judo may be a factor in osteocalcin secretion from the bone.

Different sports are associated with different BMD depending on the part of the body most impacted. For example, in kendo and tennis, the BMD of the dominant hand tended to be higher [24,25]. In the present study, wrestlers had higher BMD in their trunks, arms, and legs when compared with endurance- and non-athletes, and the same results were obtained after adjustment for body mass (**Table 2**). Judoka had higher BMD in their trunks and arms when compared to endurance- and non-athletes, but there was no difference in leg BMD between the groups. This may be a feature of combat sports, where there is repetitive whole-body impact. However, judo athletes practice "ukemi," which is a technique meant to reduce impact [26]. Additionally, there is no tackling on the legs as in wrestling. Thus, it is possible that the BMD is the same in judoka as in endurance- and in non-athletes due to the influence of this technique. Another reason for the differences observed in BMD may due to a bidirectional crosstalk from muscle to bone and from bone to muscle, which involves a complex correlation between mechanical and metabolic factors [27]. Indeed, an increase in muscle mass acts at the interface of the two organs and stimulates local bone growth by stretching collagen fibers and periosteum [28]. In this study, wrestlers had significantly larger whole and partial fat-free mass than the other groups. Thus, the BMD of wrestlers with lager skeletal muscle mass may be higher than endurance-athletes who often use the lower body, even if the BMD is adjusted by weight.

According to a previous study, BMD does not increase unless the bones endure enough impact due to exercise [29]. When bone is not impacted, sclerostin is excreted, which prevents osteoblasts from forming new bone. For this reason, it is important to obtain data regarding the appropriate amount and type of physical activity. Wrestlers have a large total energy expenditure (averaging 17.9±2.5 MJ) and physical activity level (2.6±0.3, where >2.40 is extremely active), as shown in a large physical activity study [13]. Thus, it is also highly possible that the physical activity of wrestlers influences their BMD.

While it is theoretically possible to explain differences in BMD between judoka and wrestlers according to total energy expenditure and physical activity level, unfortunately, these parameters for judoka are unknown. Hinton et al. described that BMD can be improved by high-impact and resistance training [30]. Therefore, bones may have a mechanism that enables them to make stronger new bones through activity, especially activity that causes bone impact.

In the present study, there was no collection of dietary data and causal relationships could not be clarified. However, wrestling and judo athletes who perform rapid weight loss through energy restriction for competition several times in a year did show a higher BMD. Since bone formation is increased with weight-bearing physical activity even during weight loss [31], wrestling and judo athletes may benefit from high-impact body contact during training even when they perform weight-cycling. Moreover, since ultraviolet rays from sunlight endogenously produce vitamin D [32], it has been pointed out that there may be a negative effect on the bones of athletes who participate in indoor sports and do not receive sufficient sunlight favoring bone health. However, results from this study indicate that athletes participating in indoor sports, such as a wrestling and judo, still had higher BMD than the triathlon and cycling athletes who participate in their sport outdoors. Therefore, we speculate that the effects of hormones that increase bone strength are stronger in terms of promoting BMD than the negative effects of energy restriction, rapid weight loss, and indoor sports.

There are several limitations of this study to consider. First, the present study used cross-sectional data rather than a controlled trial design, limiting the analyses of the results. Because the participants were college athletes, it was difficult to obtain blood samples and collect food records, which would have been prohibitive to their participation in the study. Food intake during college life is an important factor for obtaining peak bone mass [33]. Most important is intake of various nutrients such as protein, minerals such as calcium, phosphorus, and vitamins D, A, K, and C [34]. Therefore, it will be necessary to conduct further evaluation of energy availability, food intake, and bone mass during this period, especially in athletes [35]. In addition, all the participants were Japanese, and it has been shown that race effects BMD [16]. For future studies, it will be beneficial to compare different races with a larger sample size.

Conclusions

The results of the present study showed that weight-classified athletes such as those who participate in wrestling and judo had higher BMD when compared to endurance- and non-athletes despite undergoing rapid weight loss before competition. In addition, we found that the BMD of wrestlers was higher than that of judoka and endurance- and non-athletes when adjusted for body mass. This striking difference in BMD between the weight-classified athletes, endurance-athletes, and non-athletes could be attributed to differences in bone-loading activity irrespective of change in weight status during a competitive season. This information could be used in training protocols to increase BMD for other male young adults in further studies.

Authors' contribution

HS conceived the study and the study design; HS, EK, YT and OT conducted experiments; HS and EK performed data analysis; HS, EK, YT, OT, YY, and HT interpreted experimental results; HS prepared illustrations; HS drafted the manuscript; HS, EK, YT, OT, YY, and HT edited and revised the manuscript. All authors read and approved the final version of the manuscript.

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Conflict of interest

The authors state that there are no personal conflicts of interest.

Compliance with Ethical Standards

This study was performed in compliance with current Japanese law.

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Figure legends

Figure 1: Whole-body bone mineral density adjusted for body mass between groups

* significant difference between groups ($P<0.05$).

Figure 2: Distribution of whole-body bone mineral density z-score values for each participant separated by group

Figure 1 Click here to access/download;Figure;Figure 1.tiff

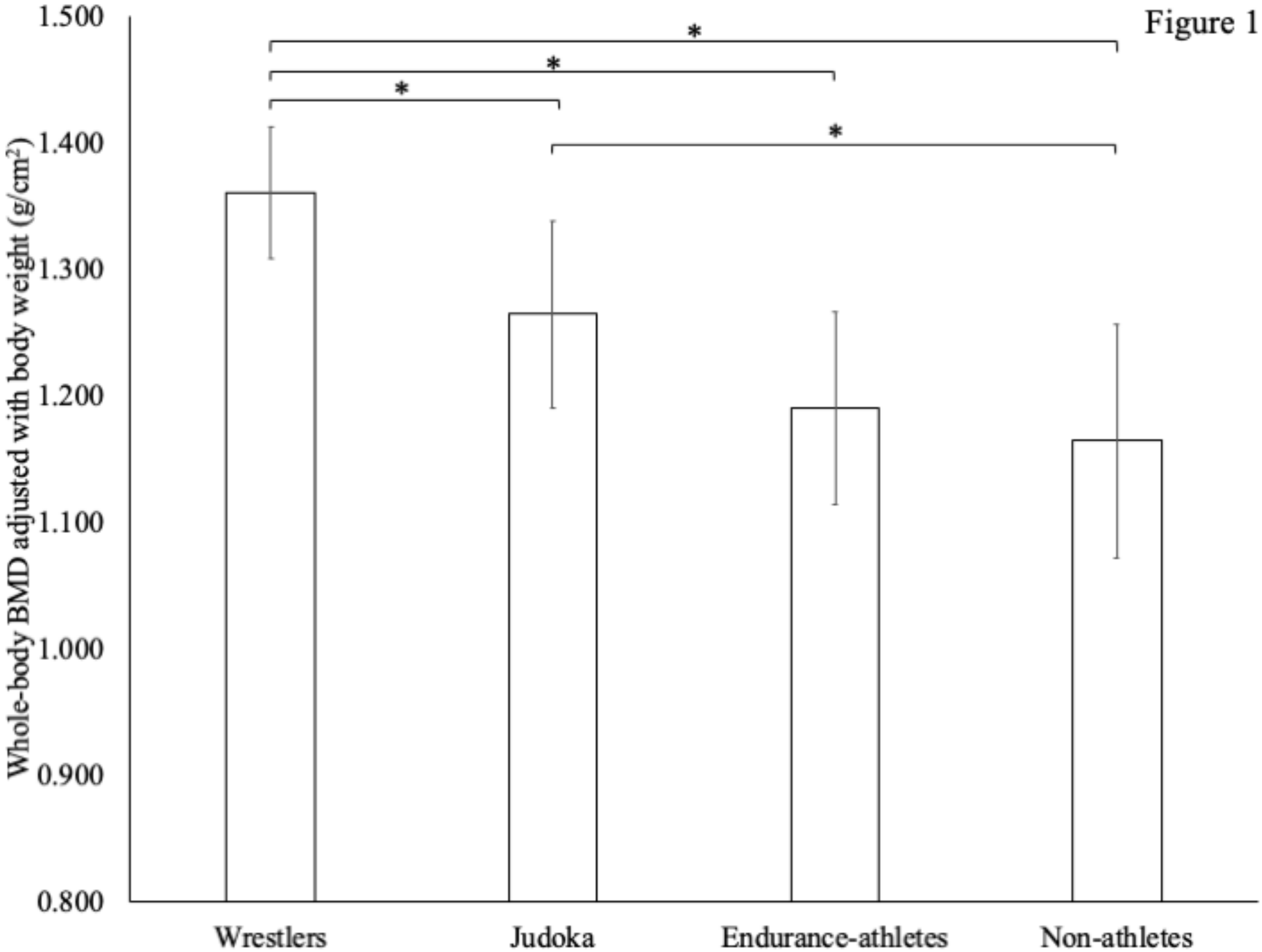

Figure 2

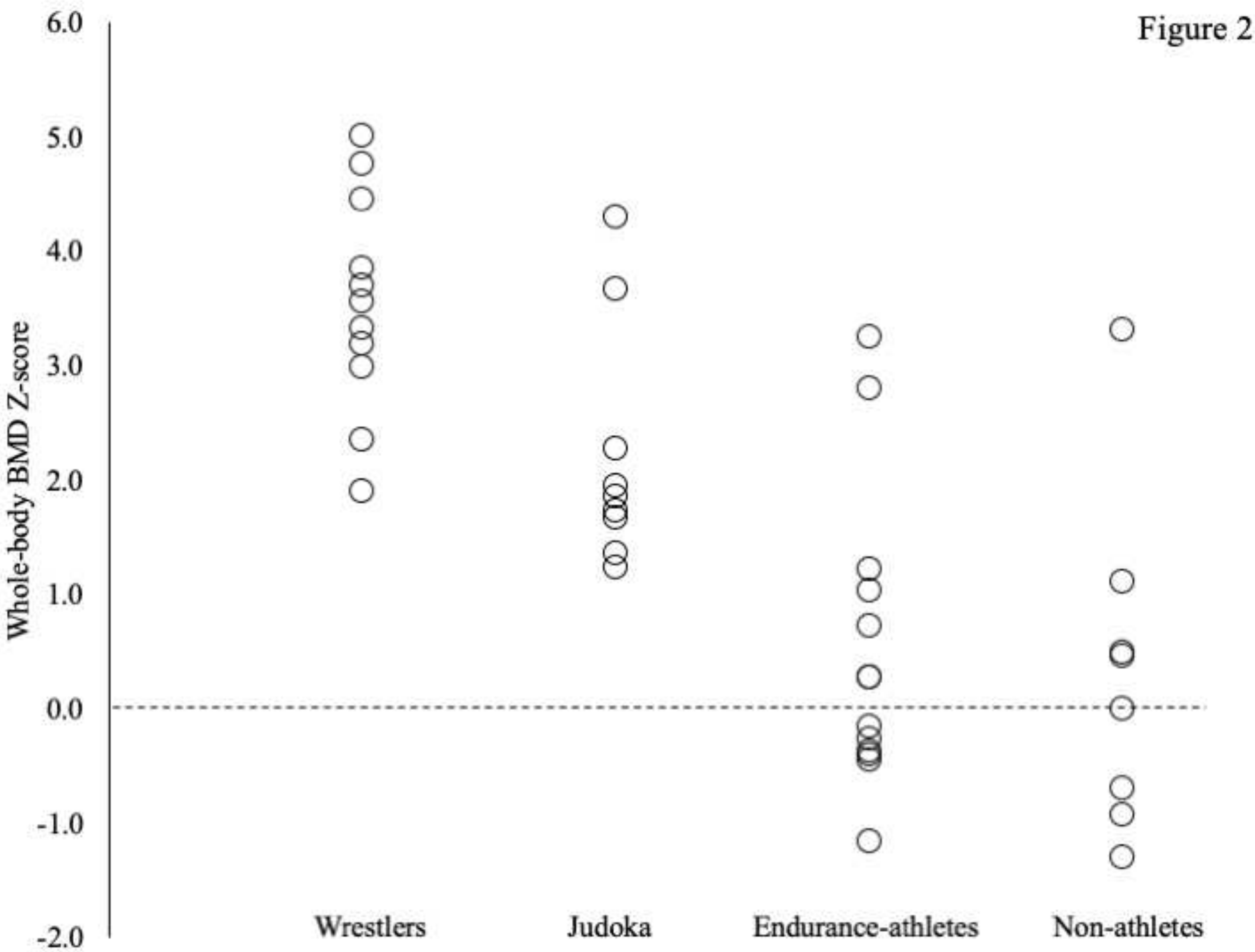

Figure 2
Whole-body BMD Z-score
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
Wrestlers
Judoka
Endurance-athletes
Non-athletes

Table 1

Table 1. Characteristics of each group

	Wrestlers	Judoka	Endurance athletes	Non-athletes	F-values	P-values
Age, years	20±1	19±1	21±2	21±4	2.194	0.11
95%CI	(20-21)	(18-19)	(19-22)	(18-24)		
Height, cm	169±4	170±8	171±5	173±4	0.826	0.49
95%CI	(166-171)	(163-176)	(167-174)	(169-176)		
Body mass, kg	73.0±7.8 [b]	79.1±10.6 [b,c]	62.5±5.8	68.9±6.5	8.88	**<0.01**
95%CI	(67.7-78.3)	(71.0-87.2)	(59.0-66.0)	(63.4-74.3)		
BMI, kg/m^2	25.6±1.7 [b,c]	27.4±2.7 [b,c]	21.4±1.6	23.0±1.9	19.191	**<0.01**
95%CI	(24.4-26.7)	(25.4-29.5)	(20.5-22.4)	(21.4-24.7)		
Percent of fat, %	11.2±1.9 [a]	15.6±2.4 [b]	11.8±2.2	14.6±4.7	5.667	**<0.01**
95%CI	(9.9-12.5)	(13.8-17.4)	(10.4-13.1)	(10.6-18.5)		
Fat mass, kg	8.2±1.8 [a]	12.4±3.1 [b]	7.4±1.7	10.3±4.4	6.822	**<0.01**
95%CI	(7.0-9.4)	(10.0-14.8)	(6.3-8.4)	(6.6-13.9)		
Fat free mass, kg	64.8±6.7 [b]	66.7±8.1 [b,c]	55.1±4.8	58.6±3.6	8.666	**<0.01**
95%CI	(60.3-69.3)	(60.5-72.9)	(52.2-58)	(55.6-61.7)		

Values are mean ± standard deviation. CI, confidence interval. Body composition was calculated using dual-energy x-ray absorptiometry

[a] significantly different in comparison to Judoka (P<0.05).

[b] significantly different in comparison to Endurance athletes (P<0.05).

Table 2. Bone mineral density

	Wrestlers	Judoka	Endurance athletes	Non-athletes	F-values	P-values
Whole-body	1.366±0.06 [a,b]	1.282±0.066 [a,b]	1.175±0.081	1.161±0.092	17.19	**<0.01**
95%CI	1.325-1.406	1.231-1.333	1.125-1.224	1.084-1.238		
Trunk	1.185±0.046 [a,b]	1.162±0.065 [a,b]	0.960±0.078	0.988±0.136	20.71	**<0.01**
95%CI	(1.154-1.216)	(1.112-1.212)	(0.912-1.007)	(0.875-1.102)		
Trunk with body weight	1.182±0.042 [a,b]	1.153±0.067 [a,b]	0.968±0.074	0.990±0.139	38.51	**<0.01**
95%CI	(1.154-1.210)	(1.101-1.204)	(0.923-1.013)	(0.874-1.105)		
Arms	0.982±0.042 [a,b]	0.955±0.037 [a,b]	0.802±0.053	0.849±0.047	6.75	**<0.01**
95%CI	(0.954-1.010)	(0.927-0.984)	(0.770-0.834)	(0.809-0.888)		
Arms with body weight	0.976±0.033 [a,b]	0.938±0.046 [a,b]	0.817±0.049	0.851±0.046	18.84	**<0.01**
95%CI	(0.954-0.998)	(0.902-0.973)	(0.788-0.847)	(0.813-0.890)		
Legs	1.422±0.090 [a,b]	1.346±0.086	1.262±0.097	1.279±0.100	31.22	**<0.01**
95%CI	(1.362-1.482)	(1.280-1.412)	(1.204-1.320)	(1.196-1.363)		
Legs with body weight	1.414±0.073 [a,b]	1.319±0.095	1.285±0.091	1.283±0.102	5.04	**<0.01**
95%CI	(1.365-1.463)	(1.247-1.392)	(1.230-1.340)	(1.197-1.369)		

Values are mean ± standard deviation. CI, confidence interval.

[a] significantly different in comparison to Endurance athletes (P<0.05).

[b] significantly different in comparison to Non-athletes (P<0.05).