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Bone Mineral Density in Competitive Athletes

Original Research

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Abstract

Introduction: The purpose of this investigation was to characterize the bone mineral density in a wide variety of competitive athletes.

Methods: A cohort of 135 athletes was assessed for body composition via dual-energy x-ray absorptiometry (DXA). These included professional mixed martial arts fighters (MMA), elite stand-up paddlers, collegiate football players, collegiate swimmers, collegiate track and field athletes, collegiate and world-class distance runners as well as a group of men and women who participated in regular heavy resistance training.

Results: In general, bone mineral density (BMD) as determined by the T-score was highest in mixed martial arts fighters (T-score = 3.1 ± 0.9) and football players (T-score = 2.7 ± 0.7) followed by resistance-trained (RT) males (T-score = 1.9 ± 1.2). RT males had a greater average T-score than RT females (T-score 1.5 ± 1.3). Based on the data from this investigation, we conclude that RT males have greater BMD as determined by the T-score than RT females. Also, MMA fighters and football players are unique in that they tend to demonstrate very high BMD (1.57 ± 0.10 and 1.60 ± 0.12 g/cm^2, respectively) with a concomitantly high T-score.

Conclusions: It is evident that the high-impact nature of football and MMA competition is conducive to producing very high bone mineral densities. However, inasmuch as this investigation is cross-sectional in nature, it is not clear if athletes are self-selected for higher bone mineral density and/or if it is the result of years of training in their respective sport.

Key Words: MMA, football, T-score, paddling, body composition

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Introduction

Bone is a dynamic mineralized connective tissue that serves many essential functions within the body. Bone provides structural support for load bearing and movement, protects internal organs, serves as a reservoir for several minerals such as calcium, phosphate, and magnesium, houses marrow that produces red blood cells, and plays a role in endocrine signaling.[1] Bone mineral density (BMD) serves as a proxy for bone health. The most widely recognized BMD test is a dual-energy x-ray absorptiometry (DXA) scan that measures bone density of the hip and spine.[2]

Regular exercise has been shown to increase BMD. For instance, 12-weeks of a combination of heavy resistance training combined with cycling increased BMD in the legs, pelvis, and lumbar spine of previously sedentary but healthy adults.[3] Five months of heavy resistance training, but not aerobic training, attenuated the loss of hip and femoral neck BMD in overweight and obese individuals.[4] A cross-sectional investigation examined the BMD of young male powerlifters, recreational trainees, and controls. Powerlifters exhibited a significantly greater BMD when the whole body and trochanter regions were measured than the low-intensity and control group, suggesting that athletes that perform competitive heavy resistance training (e.g., powerlifting) can elevate their BMD above recreational exercisers.[5] The purpose of this investigation was to assess bone mineral density in a wide variety of competitive athletes. In addition, a secondary purpose of this investigation was to compare body fat percentages between two popular modalities (i.e., Bod Pod® and DXA).

Methods

Participants

Individuals who regularly competed in a wide variety of sports volunteered for this investigation. In addition, we compared these competitive athletes to a cohort of men and women that had been resistance training for greater than one year (n=135) (See Table 1). The population included: 41 resistance-trained individuals (20 male, 21 female), 33 college football players, 17 competitive stand-up paddlers (SUP; 8 male, 9 female), 15 professional mixed martial arts fighters (15 male), 11 Division II swimmers (4 male, 7 female), 10 track and field athletes (DII and former; 5 male, 6 female), and 8 distance runners (6 DII collegiate, 2 world/national class; 6 male, 2 female). Nova Southeastern University's Human Subjects Institutional Review Board in accordance with the Helsinki Declaration approved all procedures involving human subjects, and written informed consent was obtained prior to participation.

Protocol

Subjects had their height and weight determined using a calibrated scale. BMD and body composition were assessed with a Hologic-WI DXA (*Hologic Inc., Danbury CT USA*). Quality control calibration procedures were performed on a spine phantom. Subjects wore typical tight-fitting athletic clothing and removed all metal jewelry. They were positioned supine on the DXA within the borders delineated by the scanning table. Each whole-body scan took approximately seven minutes. Percent body fat, lean body mass, fat mass, bone mineral content (BMC), and BMD were assessed. In addition, subjects had their body composition assessed via the Bod Pod® to make comparisons with the body fat percentage data from DXA. For Bod Pod testing, Subjects were tested while wearing only tight-fitting clothing (swimsuit or undergarments) and an acrylic swim cap. Thoracic gas volume was estimated for all subjects using a predictive equation integral to the Bod Pod® software. Each subject was tested at least twice per visit to ensure measurements were within acceptable error. The Bod

Pod was calibrated the mornings of the testing sessions as well as between each subject.

Statistical Analysis
All data are expressed as the mean±SD. Using the Prism 6 software, an ANOVA was utilized to determine if significant differences existed between groups. Sidak's multiple comparison test assessed which groups differed. A paired t test was used to assess the difference between Bod Pod and DXA body fat percentages.

Results

Bone mineral density and T-scores
The primary clinical end-point in this investigation was bone mineral density (g/cm^2) and their respective T-scores (Table 2 and Figures 1 and 2). It was found that MMA athletes and football players exhibited higher bone mineral density and T-scores than all other groups. There were, however, no significant differences between MMA athletes and football players. Furthermore, resistance-trained men (RT Males) exhibited higher BMD and T-scores than the RT Females thus denoting a sex difference. In general, women demonstrated lower BMD and T-scores than men. The group of athletes that had the lowest BMD and T-scores were swimmers.

Table 1 – General Physical Characteristics – Age, Sex, and Height

Type of Athlete	Sex (male/female or combined)	Age (years)	Height (cm)
College Football	Male n=33	22.3±0.8	184.1±7.3
Mixed Martial Arts	Male n=15	28.4±4.4	183.7±9.6
Resistance-Trained	Both n=41	30.6±7.2	169.0±8.8
Resistance-Trained	Male n=20	31.4±6.9	175.3±7.8
Resistance-Trained	Female n=21	29.8±7.6	163.0±4.3
Track & Field	Both n=10	21.5±5.2	173.2±7.4
Track & Field	Male n=5	23.0±7.4	179.3±4.3
Track & Field	Female n=6	20.0±1.0	167.1±3.5
Distance Running	Both n=8	30.2±12.4	170.1±2.8
Distance Running	Male n=6	22.3±2.6	170.2±3.6
Distance Running	Female n=2	46.0±0.0	170.1±0.1
Stand-up Paddlers	Both n=17	42.5±8.3	170.2±6.1
Stand-up Paddlers	Male n=8	46.1±8.7	173.0±4.2
Stand-up Paddlers	Female n=9	39.3±6.8	167.7±6.7

Swimmers	Both n=11	22.6±5.1	172.7±8.5
Swimmers	Male n=4	20.8±1.0	175.9±9.2
Swimmers	Female n=7	23.7±6.2	170.8±8.2

Data are expressed as the Mean±SD

Table 2 – Bone Mineral Content, BMD, and T-Scores

Type of Athlete	Sex (male/female or combined)	Bone mineral content (kg)	Total Bone mineral density (g/cm^2)	T-Score
College Football	Male n=33	4.32±0.47	1.60±0.12	2.7±0.7
Mixed Martial Arts#	Male n=15	3.90±0.52	1.57±0.10	3.1±0.9
Resistance-Trained	Both n=41	2.87±0.57	1.34±0.15	1.7±1.3
Resistance-Trained	Male n=20	3.35±0.37	1.44±0.12	1.9±1.2
Resistance-Trained	Female n=21	2.41±0.25	1.24±0.09	1.5±1.3
Track & Field	Both n=10	2.87±0.41	1.32±0.12	1.8±1.4
Track & Field	Male n=5	3.12±0.40	1.34±0.14	1.0±1.0
Track & Field*	Female n=6	2.65±0.28	1.30±0.11	2.4±1.5
Distance Running	Both n=6	2.64±0.26	1.28±0.08	1.1±1.0
Distance Running	Male n=6	2.58±0.30	1.27±0.10	0.5±0.6
Distance Running**	Female n=2	2.76±0.14	1.29±0.05	2.2±0.6
Stand-up Paddlers^	Both n=17	2.60±0.37	1.23±0.10	0.9±1.2
Stand-up Paddlers	Male n=8	2.76±0.35	1.24±0.10	0.4±1.0
Stand-up Paddlers	Female n=9	2.45±0.36	1.22±0.11	1.4±1.3
Swimmers	Both n=11	2.70±0.43	1.22±0.08	0.6±0.6
Swimmers	Male n=4	3.01±0.34	1.27±0.07	0.8±0.7
Swimmers	Female n=7	2.49±0.36	1.18±0.08	0.3±0.6

Data are expressed as the Mean±SD. Data derived from a DXA. *T-score available for only 4 subjects; one subject had a T-score of 4.2 thus elevating the average. **One of the runners was world-class and the other national class. #All are professional MMA fighters. ^Competitive stand-Up paddlers.

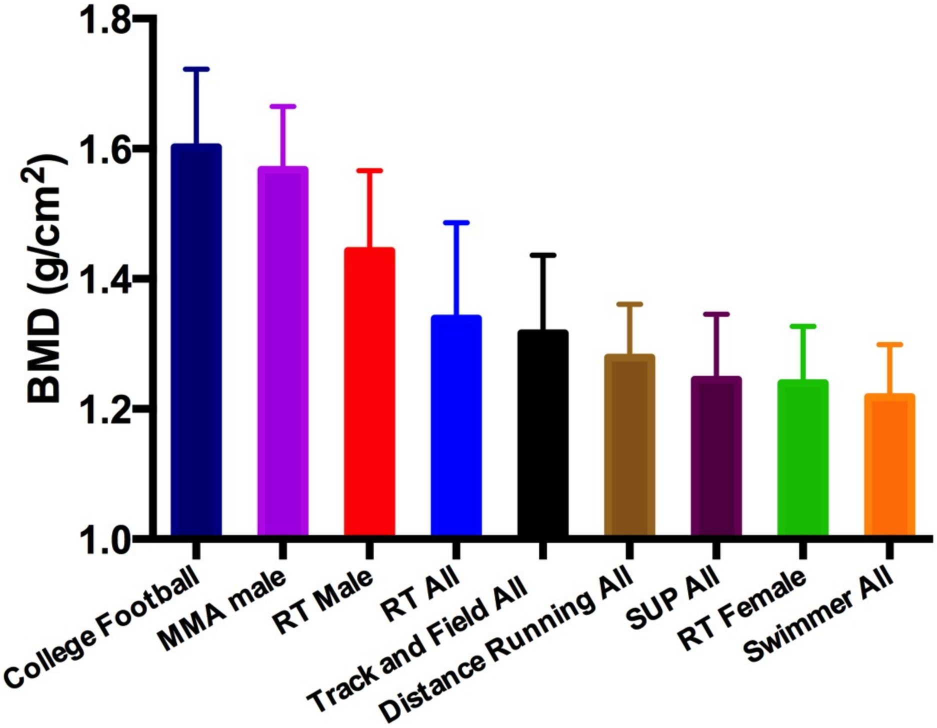

Figure 1. BMD of Athletes and Resistance-trained Individuals
Data are expressed as the Mean±SD.
Legend: BMD – bone mineral density, MMA – mixed martial arts, RT – resistance-trained, SUP – Stand-up Paddlers.
RT Male vs. RT All p=0.0467; RT All vs. MMA male p<0.0001; RT All vs. College Football p<0.0001; RT Male vs. RT Female p<0.0001; RT Male vs. Swimmer All p<0.0001; RT Male vs. College Football p<0.0002; RT Female vs. MMA Male p<0.0001; RT Female vs. College Football p<0.0001; MMA male vs. Swimmer All p<0.0001; MMA male vs. Track and Field All p<0.0001; MMA male vs. Distance Running All p<0.0001; Swimmer All vs. College Football p<0.0001; Track and Field All vs. College Football p<0.0001; Distance Running vs. College Football p<0.0001

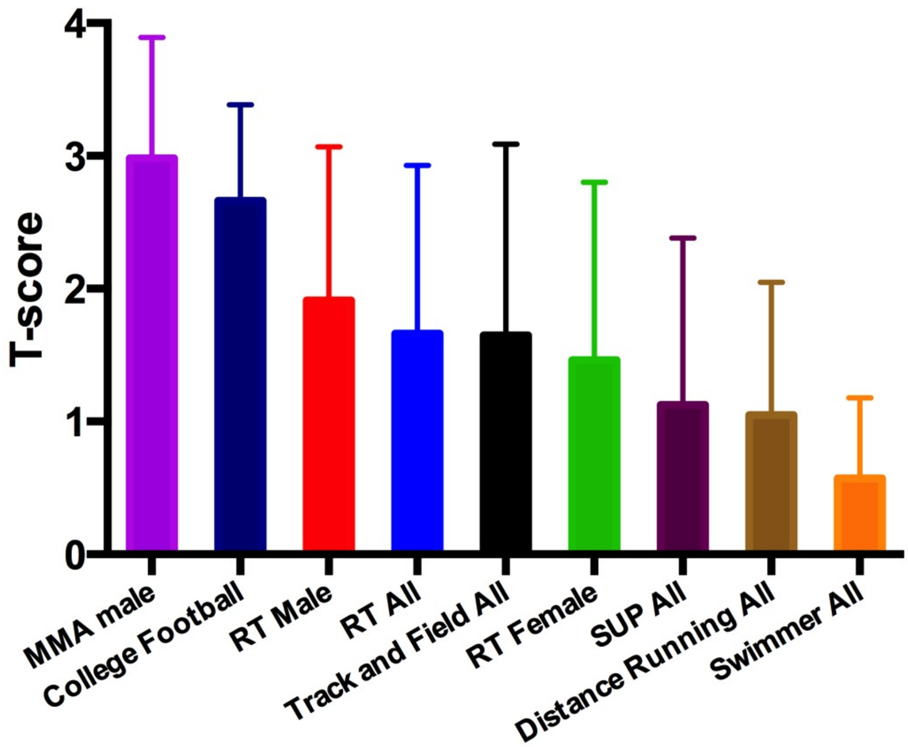

Figure 2. T-scores of Athletes and Resistance-trained Individuals.
Data are expressed as the Mean±SD.
Legend: MMA – mixed martial arts, RT – resistance-trained. SUP – Stand-up Paddlers.
RT All vs. MMA Male p=0.0036; RT All vs. College Football p=0.0055; RT Female vs. MMA Male p=0.0020; RT Female vs. College Football p=0.0038; MMA Male vs. Swimmer All p=0.0001; MMA male vs. Distance Running All p=0.0109; Swimmer All vs. College Football p=0.0003; Distance Running vs. College Football p=0.0336
T-scores reference range: normal = 1 SD (or +1 or -1) of the young adult (30 yr. old) mean. Low bone mass: -1.0 to -2.5; Osteoporosis: less than -2.5.

Lean Body Mass, Fat Mass, and Body Fat Percentage
RT males exhibited significantly greater LBM and lower body fat percentage than RT females. However, absolute fat mass was similar between RT males and RT females. In general, football players, MMA, and RT males exhibited the absolute highest LBM values due primarily to their greater absolute body weight. Among males, the lowest percent body fat tended to be found among male distance runners, track and field, swimmers, and MMA fighters. The highest percent body fat percentage among men tended to be found in resistance-trained males and stand-up paddlers. However, one should note that all male athletes, regardless of sport, exhibited low percent body fat values. (See Table 3).

Among women, there were not any differences in LBM between groups. This was due primarily to the fact that LBM in these athletes and trained individuals is largely related to total body weight. Also, there were no differences in body fat percentage between the different female athletes. Although distance runners showed the lowest body fat percentage, it should be noted that this group included only two women; and furthermore, these two individuals were world-class and national class runners. (See Table 3).

Table 3 – Lean Body Mass, Fat Mass and % Body Fat

Type of Athlete	Sex (male/female or combined)	Weight (kg)	Lean Body Mass (kg)	Fat Mass (kg)	% Body Fat
College Football	Male n=33	97.7±13.7	76.4±7.8	17.0±6.4	17.0±3.9
Mixed Martial Arts	Male n=15	90.0±12.6	71.3±9.8	13.7±3.1	15.3±1.9
Resistance-Trained	Both n=41	75.9±17.8	56.3±15.8	16.8±5.6	22.6±6.7
Resistance-Trained	Male n=20	90.1±13.7	70.1±10.4	16.6±6.5	18.2±5.1
Resistance-Trained	Female n=21	62.5±8.0	43.2±4.9	16.9±4.7	26.7±5.2
Track & Field	Both n=10	74.0±8.5	55.9±12.8	15.1±5.4	21.1±8.5
Track & Field	Male n=5	78.3±9.7	65.8±12.8	9.9±2.5	13.0±3.9
Track & Field	Female n=6	69.7±4.9	47.6±4.2	19.4±2.2	27.9±3.1
Distance Running	Both n=8	61.6±2.5	49.4±1.8	9.6±1.4	15.6±1.9
Distance Running	Male n=6	61.4±2.4	49.9±1.8	8.9±0.7	14.6±0.9
Distance Running	Female n=2	62.0±3.6	48.2±1.7	11.0±1.7	17.8±1.8
Stand-up Paddlers	Both n=17	67.0±10.6	50.0±10.5	14.4±3.5	21.9±5.5
Stand-up Paddlers	Male n=8	75.7±7.6	59.2±7.2	13.7±3.0	18.1±3.6
Stand-up Paddlers	Female n=9	59.3±6.3	41.9±4.7	14.9±3.4	25.2±4.7
Swimmers	Both n=11	71.6±9.8	53.5±9.7	16.4±5.2	22.9±7.1
Swimmers	Male n=4	80.6±7.6	63.8±4.9	12.9±3.1	16.1±3.5
Swimmers	Female n=7	66.5±6.8	46.5±3.5	18.7±5.1	27.4±4.8

Data are expressed as the Mean±SD. Data derived from a DXA.

Body Composition – Bod Pod versus DXA

In a subset of 121 athletes, we compared their body fat percentage via two methods. There were consistent differences in that overall, DXA produced % body fat values greater than the Bod Pod. In males alone, this difference was 2.8%; in females, the difference was 5.6%. (See Table 4).

Table 4 – Comparison of Body Fat Percentage – Bod Pod versus DXA

	Bod Pod	DXA	Average % Difference
Male n=70	14.5±5.6	17.3±4.1*	2.8%
Female n=51	21.3±5.9	26.9±5.6*	5.6%

Data are mean±SD. Bod Pod versus DXA in 122 subjects.
*Significantly different, $p < 0.05$
Male data p=0.0008 (DXA > Bod Pod)
Female data: p<0.0001 (DXA > Bod Pod)
Paired t test statistic

DISCUSSION

This cross-sectional study found that football players and MMA athletes have significantly greater BMD than all other tested groups of athletes, including those involved in resistance training, SUP, swimming, track & field, and distance running. To our knowledge, this is the first study to report on the BMD of adult MMA athletes. Previous research has reported on the BMD of athletes involved in boxing,[6, 7] wrestling,[8] judo/wrestling, [9] and judo/karate.[10] The average BMD of these other combat sport athletes ranged from 1.24 to 1.4 g/cm^2, which are significantly less than the 1.57 g/cm^2 observed in our study for MMA athletes. It should be noted that there were no significant differences in BMD between football players and MMA athletes despite the significantly larger size of the football players. Both sports involve very high-velocity impact and thus the stress imposed on their skeleton would seem to be quite extreme.

Bone strength is a function of several factors, including bone size, shape, stiffness, and mineralization.[11] BMD accounts for 60-70% of the variation in the compressive strength of bone tissue and remains the most useful clinical tool for estimating bone strength.[12, 13] Therefore, it is of interest to identify plausible explanations for the high BMD observed in MMA athletes in this cross-sectional study.

The most likely explanation for the high BMD observed in MMA athletes as well as football players in this study relates to a functional adaptation of the skeleton to mechanical loading, a phenomenon traditionally described by Wolff's Law and more accurately described by the mechanostat hypothesis.[14, 15] Essentially, Wolff's Law states that bone tissue adapts to the loads (or lack of) placed upon it, becoming stronger or weaker as a result. The mechanostat hypothesis builds upon this law by proposing that bone tissue perceive their total mechanical environment and compare it with what is expected for the specific habitual circumstances to determine whether bone architecture is appropriate, and then initiate an adaptive response.[16, 17]

Based on experiments conducted in animals, Chilibeck et al. proposed that exercise regimens designed to increase bone mass and strength should involve intermittent loads of high magnitude and rate, should be dynamic in nature, and involve varied and diverse patterns of stress.[18] The data from our study appears to support this notion. Resistance training involves skeletal loading of high magnitude and varied patterns of stress, but the strain is often static and applied at a relatively low rate. Aerobic activities such as running apply dynamic strains at high rates, but have a relatively low peak strain load and distribution. It is possible that the MMA fighters and football players of our study obtained the best of both worlds since their training regimen involved both resistance-training, running (various distances) and in the case of MMA athletes, impact from being punched and/or kicked; This therefore may explain their prominent levels of BMD.

Nonetheless, there does appear to be a hierarchy of strain importance in bone remodeling. Beavers et al. reported that performing resistance training attenuated the loss of hip and femoral neck BMD observed with aerobic training in overweight and obese older adults undergoing a five-month weight loss intervention.[4] Numerous cross-sectional and longitudinal studies have suggested that resistance training provides more profound stimuli to bone than aerobic training.[19] According to the mechanostat theory, bone deformation primarily regulates bone remodeling.[14, 16] Mechanical forces are needed to deform bone, and these forces are created primarily from muscle contractions and gravitational forces. Resistance training can increase muscle strength, thereby subjecting the skeleton to higher loads. An exercise-induced increase in muscle mass may also increase skeletal load through increasing gravitational forces, at least on weight-bearing bones. Thus, resistance training appears to be superior to aerobic training for increasing BMD.

However, many other factors also play a role in the osteogenic stimuli created by resistance training, which makes it difficult to separate the role of load-bearing aspects of exercise per se from the genetic, hormonal, and nutritional aspects that are modified in athletes and by exercise. The observed sex difference in BMD of our study serve as an excellent example, since men demonstrated consistently higher levels of BMD than woman regardless of sport. Even after controlling for differences in lean body mass and total bone area, males exhibit higher BMD than females.[20] Studies in twins have attributed 60-80% of the variation in bone strength to genetics.[21-23] Our cross-sectional study cannot inform causality and it is therefore possible that reverse causality explains our findings: genetic and other factors mediate the greater BMD in MMA athletes and cause them to participate in MMA rather than MMA causing the greater BMD.

Notably, swimmers had the lowest BMD in our cohort. A recent meta-analysis found that although water-based activities resulted in significantly higher BMD than remaining sedentary, it was inferior to land-based activities such as resistance training or running.[24] This study corroborated a previous systematic review suggesting that swimming is better than doing nothing for bone health, especially later in life, but that land-based sports are superior for increasing BMD.[25]

Lastly, it should be noted that when using different methods of body composition (i.e., DXA versus Bod Pod), it is evident that the actual values for body fat percentage may differ substantially (~3-6% higher values for the DXA versus the Bod Pod). Thus, it would behoove fitness professionals and scientists to be consistent in the type of body composition assessment they utilize. One can not necessarily use data from one method and make comparisons (on a subject[s]) using another method.

Media-Friendly Summary

Our cross-sectional study found that football players and MMA athletes have the highest BMD of any group of athletes. This is of course likely due to self-selection (i.e., those that can naturally withstand this kind of training are more apt to stick with the sport) as well as training. Exercise, nutrition and genes influence BMD. At the end of the day, male athletes in very high-impact sports are the ones with the most dense bones.

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