【Original Article】

Bone strength and performance parameters in Japanese collegiate American football players

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Abstract

Seventy percent of bone strength depends on adequate bone mineral density. To date, there has been little research on bone strength of Japanese collegiate American football players. The aim of the present study was to create profiles on bone strength of Japanese athletes. We evaluated the differences in the body compositions, performance test results and bone strength between: (1) Japanese collegiate American football players in skill positions and linemen; (2) data from these Japanese athletes and age-matched reference data by the LD-100, a unique quantitative ultrasonography device. In addition to significant differences in 7 of the 10 comparisons for the body compositions and performance test results by positions, there were significant correlations among the body compositions, performance test results and bone-related indices. Also, we found significant differences in all variables for the comparison between Japanese American football players' data and age-matched reference data.

In the college athletes, power training seems to enhance bone formation, mainly on outer bone. The Japanese athletes showed superiority over the age-matched reference data in all parameters. Especially, the elastic modulus of trabecular bone, a bone strength-related index that can be determined only with LD-100, was significantly higher in the American football players' data than in the reference data.

Key words: Bone formation, Resistance training, American football, Quantitative ultrasonographic device, Adaptation

I Introduction

Measurement methods using radiological techniques [1–3] have been widely used in bone-related research. Those methods, however, determine only the amount of bone mass [4]. Bone mineral density (BMD), a representative index of bone strength, has been used as a risk indicator (e.g., for osteoporosis) [1, 5] and as an index to evaluate training effect on athletes [2, 6]. Overall, 70% of bone strength is dependent on BMD [7]. As quantitative ultrasonography (QUS) sends out mechanical or elastic waves, QUS parameters are closely related to the microarchitecture and properties of bone, which play an important role in bone strength [4, 8–10].

The parameters related to mechanical strength are the ultimate strength, yield strength, elastic limit, and elasticity [4]. Among them, only elasticity can be non-destructively gained using an ultrasonic method [4]. Compared with radiologic methods, the ultrasonic method is radiation-free, inexpensive, and portable [4]. It has been pointed out, however, that ultrasonic measurements have drawbacks, such as poor reproducibility and uncertainty regarding the values of the measured items [11]. To solve such problems, LD-100 (OYO Electronics Co., Ltd., Kyoto, Japan), a new QUS device that is the only one that can measure elasticity, was developed and is continually being improved [4, 11, 12].

Previous studies have shown that LD-100 can assess the mass density (mg/cm^3) and elasticity (GPa) of cancellous bone by measuring the speed and attenuation of a ultrasonic pulse with fast and slow waves, respectively [11, 12]. One of those studies found that the fast wave is closely related to the porous network structure of trabeculae, which relies on the density and elastic factors of the trabecular organization [11]. In contrast, the slow wave is closely related to the density and elastic style of the bone marrow inside of the trabeculae [11].

To the best of our knowledge, only one study has addressed the bone strength of Japanese collegiate American football players, but the number of subjects was relatively small [13]. Thus, in the present study, our aim was to evaluate the difference in bone strength between the following groups using multiple indices of bone strength other than BMD (1) in Japanese athletes playing in skill positions in American football and linemen according to their performance and physical data; (2) in the same Japanese collegiate American football players versus age-matched reference data. Using the data derived from these comparisons, we tried to elucidate the bone characteristics of Japanese collegiate American football players from several perspectives. In this way, we can create a training menu that takes advantage of Japanese bone characteristics.

We hypothesized that resistance training on a regular basis increased bone strength. Hence, the better the muscle strength and body composition are, the stronger are the bones. Thus, (1) among the collegiate American football players, those with superior muscle strength and body composition should have stronger bones; and (2) the Japanese collegiate American football overall should exhibit bone strength superior to that revealed in age-matched reference data.

II Methods

1. Participants

Altogether, 56 Japanese collegiate American football players (mean age 20.5 ± 1.2 years) were recruited for the study during the 2013 season (Table 1). For data analysis, the players were grouped by playing position as follows: skill positions (n = 38; defensive back, linebacker, running back, tight end, wide receiver, quarterback) and linemen (n = 18; defensive and offensive linemen). Most of them started resistance training in college and engaged in regular training two to three times a week throughout the season. This study was performed according to the Declaration of Helsinki and approved by the ethics committee of Doshisha University (approval #0823). Before participation, each subject was informed of the risks and benefits of the study, after which they provided written informed consent.

2. Design and Procedures

Early in the 2013 season (March/April), we recorded each player's physical characteristics, including height, body weight, percent body fat, and lean body mass (LBM) (Table 1). We also conducted, and recorded the results from, some performance tests, including the 1-repetition maximum (1-RM) bench press, and back squat for measured values (kg), and a vertical jump (cm) [14]. Simultaneously, each player's non-dominant hand radius was analyzed using LD-100 imaging. The data regarding bone indices were the attenuation (dB), radius thickness (RaTh, mm), cortical thickness (CoTh, mm), trabecular bone density (TBD, mg/cm^3), elastic modulus of trabecular bone (EMTb, GPa), and section modulus (mm^3).

For comparison to Japanese standard data from persons of the same age(age = 20-24, n = 250) and gender (all male subjects), we referred to the study as a Non-athletes by Sai, et al. [15], which studied the CoTh, TBD, and EMTb by using LD-100(a total of 2380 participants).

3. Body Fat Measurement

We measured skinfold thickness with skinfold callipers at seven sites: triceps, subscapular, middle axillary, suprailiac, chest, abdomen, and front of the mid-thigh. The body fat was then calculated using the Jackson and Pollock formula [16] for a Japanese male [17].

Body fat (%) = [(4.97 / body density) − 4.52] × 100

4. Performance Tests

Bench press and back squat were routinely included in the regular training program and performed according to the National Strength and Conditioning Association (NSCA) guidelines [18]. Regarding 1-RM test methods for bench press and back squat, all participants' trials were visually assessed by a strength-and-conditioning coach. More detailed methods are described in our previous report [14]. We also calculated the following based on each player's body weight and vertical jump height [19].

Power ($kg{\cdot}s^{-1}$) = $\sqrt{4.9}$ (body weight) × $\sqrt{\text{jump height (m)}}$

Where the body weight was recorded in kilograms and the jump height in meters.

5. LD-100 System Measurement

The newly developed LD-100 ultrasonographic system (OYO Electronics Co., Ltd., Kyoto, Japan) can measure indices related to the microarchitecture and elasticity of bone, which play an important role in maintaining bone strength [4, 8-10] (Figure 1). The measurement method of LD-100 consists of two scanning regimens. For the first, the non-dominant side of the radius is placed between two transducers—the ultrasonic transmitter and the receiver. The bone geometry of the chosen site is scanned, and the site for the second set of scans is chosen [12]. During the second scanning, the attenuation, CoTh, TBD, and EMTb are measured [12]. More detailed methods and the scientific background of LD-100 ultrasonography are described in previous publications [4, 15].

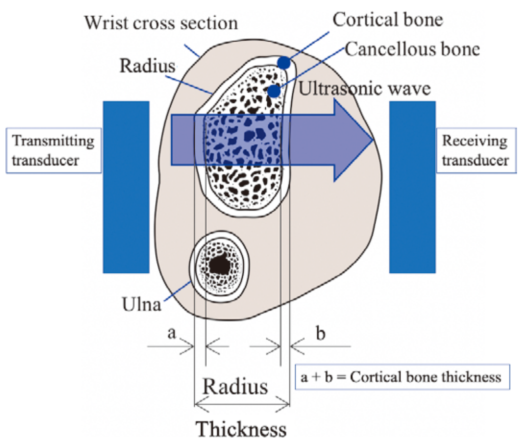

Figure 1. Schema of an ultrasonic wave passing through bone.

Ⅲ Attenuation

Attenuation, an index of bone that is measured in decibels, is the measurement of the reaction when ultrasonic wave propagates through the measurement site, which depends on the bone mass (combined cortical and cancellous bone). The larger the transmitted wave attenuation, the greater is the bone mass [13].

1. RaTh and CoTh

RaTh is the width of the outer shape of the radius (i.e., the distance between one surface of the radius and the other surface from which the ultrasonic wave was propagated [13]. CoTh is the thickness of the cortical bone outside the bone, which is calculated from a total thickness of two cortical bones in the area from which the ultrasonic wave was propagated [13].

2. TBD

TBD is the bone density per unit volume of cancellous bone. Cancellous bone is composed of mesh-like bone and bone marrow. Thus, a low TBD means that bone marrow occupies a large proportion of the bone [13].

3. EMTb

EMTb is the elasticity (GPa) of cancellous bone, which is the only parameter we can gain non-destructively to assess bone status or quality, especially from the perspective of mechanical strength [4, 12]. This value, which can be acquired only using LD-100 at present, is calculated from the speed of the sound propagating through the mesh-like bone portion of cancellous bone. Thus, the higher the number, the less distortion that is present [13].

4. Section Modulus

Section modulus (SM), measured in cubic millimeters (mm^3), is the strength against bending when assuming the radius as a cylinder with only cortical bone. This parameter was calculated using the equation.

SM (mm^3) = $\pi/32(\text{RaTh}^4 - \text{cancellous bone thickness}^4)/\text{RaTh}$

The lower the value, the easier it is for the bone to be bent and fractured [13].

Ⅳ Statistical Analysis

The Kolmogorov–Smirnov test was performed for all 16 variables and identified only 6 as normally distributed. Because most of the variables were non-normally distributed, we decided to use non-parametric tests, including Spearman's rank correlation coefficient, for comparisons between the performance tests results and bone quality. Also, we used the Mann–Whitney U test for pairwise comparisons. We then calculated the r effect size for all Mann–Whitney U tests, with 0.10–0.29 considered a small effect size, 0.30–0.49 a medium effect size, 0.50–0.69 a large effect size, ≥ 0.70 a very large effect size[20, 21]. All statistical analyses were performed by the IBM SPSS Statistics for Mac, version 24.0 (Japanese) (IBM Corp, Armonk, NY, USA). The level of significance was set at 0.05.

V Results

We confirmed that body weight, body fat, and LBM were significantly higher for linemen than for skill-position athletes ($p < 0.01$) (Table 1). Regarding the performance tests, although the skill-positions athletes jumped significantly higher than the linemen, the linemen were significantly stronger in the bench press, back squat, and power than those in skill positions ($p < 0.01$) (Table 2). There were no significant differences in bone-related indices between linemen and those in skill positions (Table 3). Performance tests and bone-related indices indicated that body weight, body fat, LBM, and power were significantly correlated with attenuation (r = 0.31, 0.27, 029 and 0.36, respectively; $p < 0.05$) (Table 4). Also, the athletes' height was significantly correlated with RaTh ($r = 0.28$, $p < 0.05$) (Table 4). A comparison between Japanese football players' data and age-matched reference data showed significant differences in all variables (CoTh, TBD, EMTb) ($p < 0.01$) (Table 5).

VI Discussion and Conclusions

1. Japanese Collegiate American-Football Players

This cross-sectional study examined the relations among bone, performance ability, and body composition for athletes involved in high-impact sports. In accordance with previous study [14], linemen (vs. those in skill positions) showed superior muscular strength (bench press, back squat) and body composition (i.e., body weight, body fat, LBM). For the correlation between the results of the over-

Table 1. Comparison of plyaing positions for physical characteristics Skill vs. Line

	All				Skill				Line				Skill vs. Line	
Variables	n	Mean±SD	Range	95%CI	n	Mean±SD	Range	95%CI	n	Mean±SD	Range	95%CI	effect size	p value
Height(cm)	56	175.2 ± 5.1	189.1 - 165.0	173.8-176.6	38	174.4 ± 5.3	165.0 - 189.1	172.6 - 176.1	18	177.0 ± 4.5	171.3 - 188.0	174.8 - 179.2	0.26	0.05
Body Weight(kg)	56	86.4 ± 12.7	66.8 - 119.1	83.0 - 8 9.8	38	79.8 ± 7.4	66.8 - 94.5	77.4 - 82.3	18	100.3 ± 9.9	87.2 - 119.1	95.3 - 105.2	0.75	<0.01
BodyFat(%)	56	21.1 ± 12.7	9.4 - 33.0	19.5 - 22.7	38	18.3 ± 4.8	9.4 - 26.3	16.7 - 19.9	18	26.9 ± 3.6	22.4 - 33.0	251 - 28.7	0.69	<0.01
LBM(kg)	56	67.6 ± 6.7	53.2 - 84.9	65.8 - 69.4	38	65.0 ± 5.3	53.2 - 73.6	63.3 - 66.8	18	73.1 ± 6.0	64.0 - 84.9	70.1 - 76.1	0.55	<0.01

Note. CI= confidence interval

Table 2. Comparison of plyaing positions for performances Skill vs. Line

	All				Skill				Line				Skill vs. Line	
Variables	n	Mean±SD	Range	95%CI	n	Mean±SD	Range	95%CI	n	Mean±SD	Range	95%CI	effect size	p value
Bench press(kg)	56	103.5±16.3	67.5 - 140.0	99.2 - 107.9	38	97.3±13.4	67.5 - 125	92.9 - 101.7	18	116.7±14.1	87.5 - 140	109.7 - 123.6	0.55	<0.01
Bench press/BW	56	1.20±0.14	0.90 - 1.50	1.17 - 1.24	38	1.2±0.14	0.90 - 1.50	1.18 - 1.27	18	1.2±0.13	0.91-1.30	1.10 - 1.23	-0.20	0.14
Squat(kg)	56	148.9±20.0	105.0 - 200.0	143.6 - 154.3	38	139.8±15.1	105.0 - 175.0	134.9 - 144.8	18	168.2±14.9	150.0 - 200.0	160.8 - 175.6	0.67	<0.01
Squat/BW	56	1.73±0.16	1.30 - 2.10	1.68 - 1.77	38	1.7±0.16	1.30 - 2.10	1.69 - 1.80	18	1.7±0.16	1.30 - 1.90	1.60 - 1.76	-0.14	0.30
Vertical Jump(cm)	56	61.6±7.8	30.0 - 80.0	59.5 - 63.7	38	64.0±8.1	30.0 - 80.0	61.4 - 66.7	18	56.5±3.7	50.0 - 63.0	54.7 - 58.3	-0.61	<0.01
Power($kg \cdot s^{-1}$)	56	149.3±20.1	90.1 - 200.4	143.9 - 154.7	38	141.0±16.2	90.1 - 167.3	135.7 - 146.4	18	166.6±16.4	144.4 - 200.4	158.5 - 174.8	0.60	<0.01

Note. BW = body weight; CI= confidence interval

Table 3. Comparison of plyaing positions for bone qualities Skill vs. Line

	All				Skill				Line				Skill vs. Line	
Variables	n	Mean±SD	Range	95%CI	n	Mean±SD	Range	95%CI	n	Mean±SD	Range	95%CI	effect size	p value
Attenuation(dB)	56	44.5±4.0	34.2 - 54.1	43.5 - 45.6	38	44.1±3.9	34.2 - 53.2	42.9 - 45.4	18	45.3±4.0	37.2 - 54.1	43.4 - 47.3	0.15	0.25
RaTh(mm)	56	13.4±1.2	10.9 - 17.8	13.0 - 13.7	38	13.2±1.2	10.9 - 15.7	12.8 - 13.6	18	13.6±1.4	12.1 - 17.8	13.0 - 14.3	0.11	0.39
CoTh (mm)	56	6.6±1.5	4.0 - 9.6	6.2 - 7.0	38	6.5±1.5	4.0 - 9.6	6.1 - 7.0	18	6.7±1.6	4.6 - 9.6	5.9 - 7.4	0.03	0.84
TBD (mg/cm^3)	56	313.8±102.4	156.6 - 776.7	286.4 - 341.3	38	313.6±91.1	156.6 - 557.5	283.7 - 343.6	18	314.3±125.9	197.2 - 776.7	251.7 - 376.9	-0.05	0.70
EMTb(GPa)	56	5.9±4.2	3.0 - 24.7	4.8 - 7.0	38	6.5±4.9	3.0 - 24.7	4.9 - 8.1	18	4.6±1.4	3.0 - 8.8	4.0 - 5.3	-0.17	0.21
SM (mm^3)	56	220.5±65.4	105.2 - 521.4	203.0 - 238.0	38	213.5±54.1	105.2 - 371.2	195.7 - 231.7	18	235.3±84.5	150.8 - 521.4	193.3 - 277.3	0.09	0.50

Note. RaTh = Radius thickness; CoTh = Cortical thickness; TBD=Trabecular bone density; EMTb = Elastic modulus of trabecular bone; SM = Section modulus

Table 4. Spearman correlation coefficients among the physical characteristecs, performance tests results and bone-related indexes

Variables	Attenuation(dB)	RaTh(mm)	CoTh (mm)	TBD (mg/cm^3)	EMTb(GPa)	SM(mm^3)
Height(cm)	0.14	0.28*	-0.16	-0.12	-0.26	0.22
Body Weight(kg)	0.31*	0.15	0.19	0.18	0.05	0.18
BodyFat(%)	0.27*	-0.05	0.24	0.23	0.14	0.02
LBM(kg)	0.29*	0.25	0.07	0.08	-0.04	0.23
Bench press(kg)	0.20	0.11	0.23	0.16	0.16	0.13
Bench press/BW	-0.15	0.02	0.07	-0.04	0.13	-0.01
Squat(kg)	0.21	0.06	0.26	0.19	0.15	0.07
Squat/BW	-0.11	-0.18	0.13	0.07	0.19	-0.18
Vertical Jump(cm)	-0.01	0.15	-0.15	-0.13	-0.07	0.11
Power(kg·s^{-1})	0.36**	0.21	0.13	0.16	0.03	0.21

Note. *$p<0.05$; **$p<0.01$; BW = body weigtht; RaTh = Radius thickness; CoTh = Cortical thickness; TBD = Trabecular bone density; EMTb = Elastic modulus of trabecular bone; SM = Section modulus

Table 5. Comparison of bone qualities Athletes vs. age-matched refrence data

	Athletes		Non-athletes			
	n	Mean±SD	n	Mean±SD	t	p value
CoTh (mm)	56	6.6±1.5	250	5.2±1.0	6.58	<0.01
TBD (mg/cm^3)	56	313.8±102.4	250	241.8±67.8	5.27	<0.01
EMTb(GPa)	56	5.9±4.2	250	4.1±1.5	3.25	<0.01

Note. CoTh = Cortical thickness; TBD = Trabecular bone density; EMTb = Elastic modulus of trabecular bone all performance test and bone parameters, we found a positive relation between RaTh and the participant's height. Because RaTh is the width of the outer shape of the radius, it can be speculated that, as an individual's height increases, bone responds by expanding its width. However, the positive correlation between these two parameters (RaTh and height) still remain unclear. Thus, there is needed for further study for this finding.

There were two other interesting findings. First, attenuation, which is related to bone mass (including cortical and cancellous bone), is positively correlated with body weight, body fat, and LBM. In support of our findings, other studies have reported positive relations among bone mass, body weight, and LBM [22] as well as body fat [23]. It seems that, as body weight (composed of body fat and LBM) increases, bone increases its mass to support the added weight.

Second, power is positively correlated with attenuation, exhibiting the highest correlation coefficient in this study. As already noted, attenuation relates to bone mass (including cortical and cancellous bone). In support of our finding, Bass, et al [24]. found that exercise-induced bone acquisition occurs mainly on the surfaces of cortical bone, especially in the endocortical area, during the postpubertal period, which does not necessarily reflect improved bone density. In this study, there was no significant relation between the TBD (which is volume density based only on cancellous bone) and power. Thus, when combined, our findings suggest that the positive relation between power and bone mass acquired by attenuation in this study is not due to increased cancellous bone but mostly to increased cortical bone.

This finding is significant because, to our knowledge, no one has examined the relation between bone formation and power. Although Nichols, et al [25]. reported that muscular strength is most closely associated with BMD, which is similar to attenuation because BMD measured by dual-energy X-ray absorptiometry is the area density calculated from cortical bone and cancellous bone. Power is not simple muscular strength, but a product of muscular strength and speed.

This result may also indicate that power training (e.g., Olympic lifting), defined as medium-to high-resistance training accompanied by rapid movement in many directions, seems to cause higher impact, more tension, and more compression force, thereby playing an important role in developing bone [6, 26-28]. Hence, power training may effectively promote bone growth.

2. Japanese Collegiate American Football Players vs. Age-Matched Reference

Compared with the age-matched reference the Japanese collegiate American football players were significantly higher for all three measurements. In this case, most of the football players had been engaged in regular resistance training two to three times a week since they entered the university. As already noted, superior muscular strength and resistance training with tension and compression force enhance bone growth, which is closely related to higher CoTh and TBD. This can explain why the CoTh and TBD of athletes were significantly higher than those in the age-matched reference data. Also, the sports specific movements related to American football such as blocking, catching and tackling, mainly using upper extremities, may enhance higher CoTh and TBD.

In line with our study, previous trials of athletes using LD-100 ultrasonography [29, 30] showed that the CoTh and TBD were significantly higher in athletes than in the controls. In contrast, Ozaki, et al [31]. reported that TBD and attenuation were significantly greater for an obese group than for the standard-body and thin groups, although the CoTh was significantly lower in the obese group than in the two non-obese groups. This discrepancy was explained by the dietary habits and excess visceral fat of the obese group. Thus, when using LD-100 ultrasonography, which could uniquely separately identify CoTh and TBD, our findings suggest that, although TBD, body weight, and the amount of resistance training are positively related, CoTh was most likely to be increased by resistance training, regardless of body weight.

The higher EMTb in the football players means that it is more difficult to bend or change shape. Mano, et al [12]. reported that EMTb measured by LD-100 was strongly positively correlated with the BMD measured by peripheral quantitative CT, which is reported as the volume density (mg/cm^3) based on only cancellous bone ($r = 0.80$). Thus, higher EMTb for the football players was highly likely to be associated with higher TBD as a result of the above-mentioned regular, long-term training. Again, EMTb is a bone strength-related index that can be determined only with LD-100. It is one of the bone strength-related indices other than BMD that has been reported to be related to the effect of resistance training [32] or high-impact hits during sports-related activities [3, 33]. The finding that EMTb was present at a higher level in the football players is significant in the current study because it is highly likely to be improved mainly because of the regular resistance training.

This study had some limitations that must be taken into consideration. First, it is cross-sectional and is not a long-term investigation of the effect of resistance training on bone. Also, we did not investigate the state of the participants' bones before starting resistance training. Simultaneously, the exercise status of the reference group is unknown. Thus, further study is needed to examine the effect of long-term regular resistance training on bones comparing the controls that is matched for exercise status.

In conclusion, because the subjects of this study were Japanese collegiate American football players, most of whom started regular resistance training when they entered the university, we could investigate the situation of bone adaptation over a relatively short term. As hypothesized, a comparison among the Japanese collegiate American football players showed that the players with better power and body composition (e.g., height, body weight, LBM) had higher bone strength indices. In addition, when compared with the age-matched reference data, the bone strength of the Japanese collegiate American football players showed excellent overall values.

We pinpointed some key findings. First, within each of these college athletes, the resistance training appeared to mostly affect the outer bone, with little effect on the inner (e.g., cancellous) bone. Second, power training, which causes more tension and compression, seems to be an effective training method for enhancing bone formation. Third, the Japanese collegiate American football players showed TBD, CoTh, and EMTb values that were superior to those found in the age-matched reference data. Especially, CoTh seemed to be the most influenced by regular resistance training. Finally, although the effect on BMD by resistance training has been reported, the current study confirmed the possible influence of resistance training on EMTb, which is a new indicator of bone strength gained only with the use of LD-100 ultrasonography.

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IX Disclosure statement (Conflict of interest)

There is no conflict of interest.

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