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Effects of Special Physical Characteristics and Exercise on Bone Mineral Density in Sumo Wrestlers

Noriko TSUKAHARA, Naomi OMI and Ikuko EZAWA

School of Home Economics, Japan Women's University, Bunkyo-ku, Tokyo 112-8681, Japan

Sumo is the national sport of Japan, and Sumo wrestlers have a specific diet, special physical characteristics and do a great deal of practice for their sport. These factors may markedly affect the bones. We observed for 1 year the effects of the physical characteristics, daily diet, and physical activities of sumo wrestlers on bone mineral density (BMD) and compared their BMD with that of age-matched male students as controls. BMD values for the lumbar spine, humerus, and femur of sumo wrestlers were higher than those of the controls ($p<0.001$) and were markedly correlated with the physical characteristics of the sumo wrestlers. Accordingly, the most important factors for sumo wrestlers to increase BMD may be improvement of their physique and enhancement of skeletal muscle strength. Sumo wrestlers 1-2 years after entering a stable showed increased BMD of the diaphysis of the humerus and femur, suggesting that the diaphysis is affected by weight and practice (load and mechanical stress). In sumo wrestlers with 6-8 years of experience, BMD of the femur proximal metaphysis was increased. This finding suggests that stamping in the ring, an exercise specific to sumo, increases BMD in each bone part.

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INTRODUCTION

It is well known that dietary habits and physical activities affect bone metabolism.[1)2)] It has been reported that there is a positive correlation between bone mineral density (BMD) and physique[3)4)] and that there is higher BMD in athletes than in the general population with the same age range without regular exercise habits.[5)-7)] In sumo, the national sport of Japan, sumo wrestlers have a specific diet, special physical characteristics,[8)] and do a great deal of practice for their sport. These factors may markedly affect bones. Owing to the particular characteristics of this sport, practice methods and dietary habits differ from those in other sports. Moreover, the risk of fractures is very high. Therefore, as part of the health management of sumo wrestlers, it is important that he knows his own BMD and understands the state of his dietary habits to enhance his awareness of health. In this study, the effects of the physical characteristics, daily diet, and physical activities on BMD in sumo wrestlers were investigated. In addition, the change in sumo wrestlers' BMD over 1 year was compared with that in age-matched male students as controls.

SUBJECTS AND METHODS

Subjects

The subjects were 10 sumo wrestlers (aged 17-27 years) in the Azumaseki stable whose change in BMD could be observed for 1 year, and 12 male students (aged 19-25 years) who lived in Tokyo and had no regular exercise habits, as age-matched controls (mean ages: 23.2 ± 3.0 and 21.4 ± 1.7 years, respectively, as mean$\pm$SD; p value was 0.097). In 6 of the controls, who were randomly selected, the change in BMD could be observed over 1 year. Informed consent for this study was obtained from each subject and the Azumaseki stable. The investigation was carried out according to the spirit of the Helsinki Declaration.

Methods

1. Investigation of physical characteristics

Physical characteristics included body weight, body height, chest circumference, girth, body thickness, and foot size. The body mass index (BMI, kg/m^2) was

calculated from body height and body weight. The body fat ratio was measured by a bioelectrical impedance analysis (BIA; model SIF-891, Japan Light Service).

2. Measurement of BMD

BMD of the lumbar spine (L1-L4) and of the whole body was measured by the DXA method (QDR-1500, Hologic). BMD of the whole body was analyzed in the proximal metaphysis, diaphysis, and the distal metaphysis of the right humerus, and in the proximal metaphysis and diaphysis of the right femur. These BMD values were calculated by selecting the software program for a subregion on our DXA equipment. In the subregion analysis, the size and location of the region of interest were established, as well as a 10×12 pixel rectangle at the center of the image in each part of the bone area, and we compared the same size and location in relation to the subject's anatomy for each scan. In both the sumo wrestlers and the controls, BMD of the same bone parts were also measured after 1 year, and the rate of change during the year was calculated. The coefficient of variance of the lumbar spine phantom BMD for our bone densitometer was 0.35%/year.

3. Nutritional survey and questionnaire of daily living and dietary habits

A dietary survey for 2 days of 2 meals/day (sumo wrestlers have two meals each day) was carried out in the stable. For the controls, a dietary survey for 3 days was carried out by the detention method, by which each subject was given a dietary record-keeping form to keep a food diary for 3 days, the contents of which were confirmed by an interview when the questionnaire was collected. A survey of living and dietary habits was also carried out by interviewing individual wrestlers and controls.

4. Statistical analysis

Student's *t*-test was used to identify significant differences between the mean value of the wrestler's group and the control group. A comparison of the BMD mean value of the two groups would not fit an analysis of covariance (ANCOVA) adjusted to the body weight, so Student's *t*-test was used. A simple linear regression was used to find a correlation between BMD and other parameters by using High Quality Analysis Libraries for Business and Academic Users (Gendai-Sugakusha, Kyoto, Japan). $p<0.05$ is considered significant.

RESULTS

The physical characteristics and exercise history are shown in Table 1. The sumo wrestlers from Hawaii showed higher values for body height, body weight, BMI, girth, and body thickness than the Japanese sumo wrestlers. Wrestler 1 (yokozuna) showed high body weight and BMI, but a low body fat ratio and a high lean body mass (LBM) when compared with the other wrestlers. Exercise history before entering the stable mainly included judo, wrestling, basketball, and football. Of the controls, only 2 had an exercise history, including swimming and martial arts.

Table 2 shows BMD values for the six sites. In each part, BMD for the sumo wrestlers was significantly higher ($p<0.01$, $p<0.001$) than for the controls. There were no significant differences in the two groups between BMD of the right side and left side of the femur (not shown in the table). BMD measurement of the lumbar spine was impossible in 2 wrestlers with a body thickness of 38 or 39 cm.

Factors (physical characteristics and exercise history) that were significantly correlated with BMD in the sumo wrestlers are shown in Table 3. BMD of the humerus and femur, especially that of the diaphysis, were markedly correlated with many physical factors. Figures 1 and 2 show BMD values in each part that were positively correlated with total exercise history (years; exercise history before and after entering the stable) and body weight. A significant positive correlation was observed between total exercise history and the femur diaphysis, humerus diaphysis and distal metaphysis. Total exercise history was not associated with the humerus or femur proximal metaphysis. BMD of the lumbar spine and the femur proximal metaphysis was not associated with body weight. Concerning the rank of the sumo wrestlers, their physical characteristics of LBM (lean body mass), body height, body weight, chest, BMI, girth, and foot size increased with rank. These data suggest that many physical factors may be associated with rank. Moreover, BMD values in each part increased with rank, especially the femur proximal metaphysis and diaphysis, and the humerus diaphysis, as shown in Fig. 3.

Figure 4 shows changes during 1 year of the BMD values in each part for each sumo wrestler and control. With the sumo wrestlers, the results were evaluated 1-2 years after entering the stable and for those with 6-8 years of experience. The sumo wrestlers with 1-2 years of experience ($N=3$) showed the smallest rate of change in the femur proximal metaphysis. The sumo wrestlers with 6-8 years of experience ($N=7$), although individual differences

Table 1. Physical characteristics of the sumo wrestlers and controls

Rank	Home town	Age	Body height (m)	Body weight (kg)	BMI*1 (kg/m²)	Chest (cm)	Girth (cm)	Thickness (cm)	Body fat (%)	LBM*2 (kg)	Exercise 1*3 (year)	Exercise 2*4 (year)
1. Yokozuna	Hawaii	25	2.040	227.0	54.6	168.0	161.5	39.0	38.2	140.3	7.0	13.0
2. Makushita	Hawaii	27	1.920	195.0	52.9	152.0	148.0	38.0	54.3	89.1	8.5	7.0
3. Makushita	Saitama	23	1.810	158.0	48.2	156.0	140.0	33.0	41.3	92.7	9.0	8.0
4. 3-danme	Hawaii	21	1.920	190.0	51.5	143.0	154.5	35.5	51.2	92.7	3.0	11.0
5. 3-danme	Niigata	25	1.760	146.5	47.3	142.0	138.0	34.5	48.6	75.3	7.0	8.0
6. 3-danme	Niigata	25	1.880	131.0	37.1	123.0	109.0	27.0	30.2	91.4	9.0	3.0
7. 3-danme	Kanagawa	25	1.830	118.0	35.2	127.0	105.0	30.0	32.0	80.2	9.0	3.0
8. 3-danme	Osaka	20	1.830	118.0	35.2	120.0	114.0	28.5	30.0	82.6	2.0	4.0
9. Jonokuchi	Okayama	24	1.780	120.1	37.9	125.0	117.0	30.0	37.8	74.6	7.0	5.0
10. Jonokuchi	Gunma	17	1.830	116.0	34.6	123.0	120.0	27.0	27.6	84.0	2.0	0
	N	10										
	Mean	23.2	1.860	152.0	43.5	137.9	130.70	32.3	39.1	90.3	6.4	6.2
	SD	3.0	0.083	39.5	8.2	16.8	20.18	4.4	9.5	18.8	2.9	4.0
Control*5	*N*	12										
	Mean	21.4	1.719	66.8	22.5	89.1	80.4	19.4	21.7	52.1	1.9*6	
	SD	1.7	0.071	10.7	2.8	5.6	6.4	2.1	5.3	7.6	2.9	

*1 Body mass index. *2 Lean body mass. *3 Exercise history after entering the stable. *4 Exercise history before entering the stable. *5 Age-matched male students (no significant age difference between sumo wrestlers and controls, $p=0.097$). *6 Exercise history. The ranks of the sumo wrestlers are yokozuna, ozeki, sekiwake, komusubi, maegashira, juryo, makushita, 3-danme, jonidan, and jonokuchi. In this study, there were 3 sumo wrestlers from Hawaii, including a yokozuna. They showed higher values than the Japanese wrestlers in body height, body weight, BMI, girth, and body thickness. With the controls, the body height and body weight were similar to the standard values in age-matched Japanese. Only two students had an exercise history.

Table 2. Bone mineral density of the sumo wrestlers and controls

Rank		Lumbar spine (g/cm^2)	Humerus proximal metaphysis (g/cm^2) (R)	Humerus diaphysis (g/cm^2) (R)	Humerus distal metaphysis (g/cm^2) (R)	Femur proximal metaphysis (g/cm^2) (R)	Femur proximal metaphysis (g/cm^2) (L)	Femur diaphysis (g/cm^2) (R) *1	Femur diaphysis (g/cm^2) (L) *2
1. Yokozuna		not analyzed	1.629	1.958	1.830	2.272	2.263	2.668	2.704
2. Makushita		not analyzed	1.679	1.908	2.002	1.923	2.038	2.302	2.233
3. Makushita		1.411	1.292	1.705	1.947	1.940	2.002	2.300	2.211
4. 3-danme		1.308	1.291	1.555	1.790	1.754	1.549	2.188	2.274
5. 3-danme		1.290	1.239	1.574	1.538	1.963	2.037	2.150	2.124
6. 3-danme		1.512	1.509	1.751	1.580	2.013	1.983	2.228	2.211
7. 3-danme		1.232	1.042	1.316	1.295	1.722	1.756	1.938	1.932
8. 3-danme		1.286	1.172	1.359	1.412	1.773	1.837	1.855	2.034
9. Jonokuchi		1.257	1.265	1.555	1.636	1.985	1.993	2.123	1.990
10. Jonokuchi		1.124	1.264	1.488	1.321	1.812	1.840	1.814	1.689
	N	8	10	10	10	10	10	10	10
	Mean	1.303***	1.338***	1.617***	1.635***	1.916***	1.930***	2.157**	2.140***
	SD	0.117	0.203	0.213	0.252	0.163	0.194	0.251	0.266
Control	*N*	12							
	Mean	0.973	0.940	1.147	1.074	1.438	1.452	1.750	1.702
	SD	0.106	0.115	0.144	0.146	0.231	0.231	0.256	0.245

*1 R: right side. *2 L: left side. $^{**}p<0.01$, $^{***}p<0.001$ (sumo wrestler *versus* control). Two sumo wrestlers were not analyzed for lumbar spine BMD because their body thickness was 39 and 38 cm. The average BMD of the sumo wrestlers was significantly higher than that of the controls.

Table 3. Correlation between BMD of sumo wrestlers and the association values by a simple linear regression analysis

	Lumbar spine	Humerus proximal metaphysis	Humerus diaphysis	Humerus distal metaphysis	Femur proximal metaphysis	Femur diaphysis
$p<0.001$						Total-Ex* (0.895)
$p<0.01$		Foot size (0.744)	Body weight (0.781) Chest (0.749)	Body weight (0.785) BMI (0.851) Chest (0.798) Girth (0.771) Thickness (0.751) Total-Ex (0.750)		Body weight (0.855) BMI (0.813) Chest (0.857) Thickness (0.766) LBM (0.782)
$p<0.05$		Body height (0.712) Body weight (0.722) LBM (0.625)	Body height (0.650) BMI (0.734) Girth (0.669) Foot size (0.720) Thickness (0.651) LBM (0.674) Total-Ex (0.673)	Foot size (0.623) Body fat (0.721)	LBM (0.707)	Body height (0.675) Girth (0.736) Foot size (0.718)

( ): correlataon coefficient. *Total-Ex: total exercise history (before and after entering the stable). BMD of the lumbar spine in the sumo wrestlers was not associated with any factor. BMD of the humerus diaphysis and distal metaphysis, and of the femur diaphysis was correlated with many physical factors.

were marked and scattering was observed, showed a significantly higher rate of change in the femur proximal metaphysis than that in the humerus diaphysis ($p<0.05$).

Table 4 shows the nutritional state of the sumo wrestlers and controls.

A dietary survey of the sumo wrestlers (2 meals/day) for 2 days showed insufficient mean intakes of calcium, V. B1 and V. B2. The PFC ratio (ratio of the energy of protein, fat or carbohydrate to total energy) was 16.0% for protein, 28.2% for fat, and 55.8% for carbohydrate.

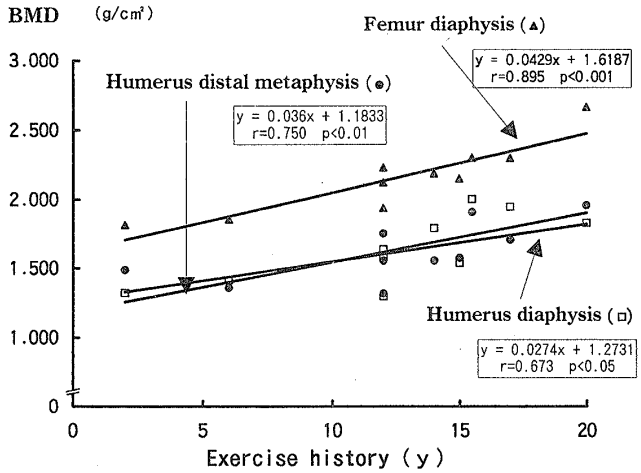

Fig. 1. Association between exercise history (years) and BMD

Total exercise history (years of exercise history before and after entering the stable) is significantly correlated with BMD of the femur diaphysis, humerus distal metaphysis, and humerus diaphysis ($r=0.895$, $p<0.001$; $r=0.750$, $p<0.01$; and $r=0.573$, $p<0.05$, respectively).

With the controls, the intakes of energy, protein, calcium, iron, V. A, V. B1, and V. B2 were also insufficient, their sufficiency rates being 86.7, 94.1, 58.3, 81.7, 71.5, 92.5 and 89.8%, respectively. In particular, the calcium intake was below 60% of the recommended daily allowance. The PFC ratio was 13.9 % for protein, 28.9 % for fat, and 57.2 % for carbohydrate.

DISCUSSION

The daily living style, including diet, is specific in sumo. In addition, since physical characteristics and skills markedly affect a sumo wrestler's performance, body weight must be increased to a certain degree. Therefore, sumo wrestlers have specific physical characteristics and do a great deal of practice, which may affect their bones. However, there have been no studies on the relationship between the physical characteristics and bones of sumo wrestlers in Japan.

The physical characteristics of sumo wrestlers are known to be superior to those of the general population. In this study, the sumo wrestlers from Hawaii showed higher values for physical characteris-

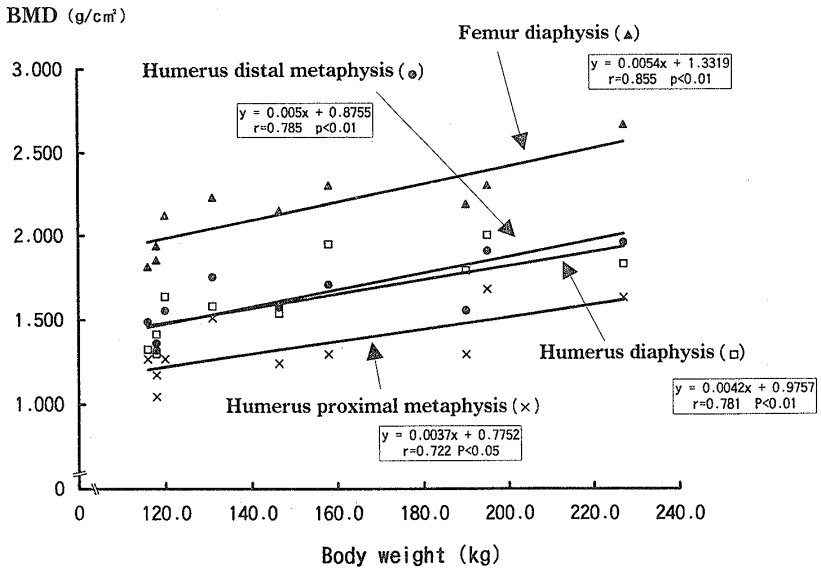

Fig. 2. Association between body weight and BMD

Body weight is significantly correlated with BMD of the femur diaphysis, humerus distal metaphysis, humerus diaphysis, and humerus proximal diaphysis ($r=0.855$, $p<0.01$; $r=0.785$, $p<0.01$; $r=0.781$, $p<0.01$; and $r=0.722$, $p<0.05$, respectively).

tics (body height, body weight, BMI, and girth) than the Japanese sumo wrestlers, which may be attributed to racial differences and daily habits, including diet, before entering the stable.

Many studies have suggested the marked effects of physique on bone metabolism. In particular, Nishizawa *et al.*[9] and Yoshikawa and Norimatsu[10] have reported a positive correlation between BMD and body weight, as well as body fat ratio. We[1][11] have previously reported a positive correlation between the BMD values of the lumbar spine and body weight as well as the body mass index. As shown in Table 3, the BMD values in each part of the humerus and femur were positively correlated with the physical characteristics. However, no significant difference was observed between BMD of the lumbar spine and physical characteristics. These results may be attributable to the abnormal soft tissue body composition of the sumo wrestlers as well as to the large body thickness. Moreover, as shown in Table 2, this result may also be due to the detection limit of the measurement equipment that did not enable an analysis of the BMD value for the lumbar spine of 2 wrestlers with a body thickness of 38 or 39 cm. Sofue [12] and Mazess *et al.*[13] have evaluated the *in vivo* effects of body thickness (up to 25 cm) and soft tissue on the accuracy of apparatus by using an acrylic water phantom or water. However, there have been no *in vitro* studies that are relevant to the present report.

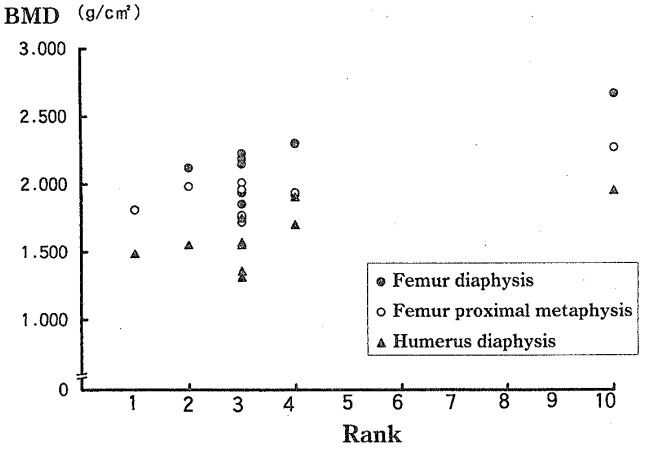

Fig. 3. BMD value according to the rank of the sumo wrestler

The femur proximal metaphysis and diaphysis and the humerus diaphysis shown in this figure increased with rank. Rank: 1, jonokuchi; 2, jonidan; 3, 3-danme; 4, makushita; 5, juryo; 6, maegashira; 7, komusubi; 8, sekiwake; 9, ozeki; 10, yokozuna.

Concerning the effects of exercise on BMD, Miyamoto and Ishiko[14] have investigated BMD for each bone part of male college student athletes and non-athletes, and observed significantly higher BMD values for the lumbar spine and femur of athletes. As shown in Table 3, the factors affecting BMD were not only physical characteristics but also total exercise history (years of exercise history before and after entering the stable). These findings suggest that BMD in young males was markedly affected by exercise as well as by physical characteristics. In sumo wrestlers, the humerus diaphysis and distal

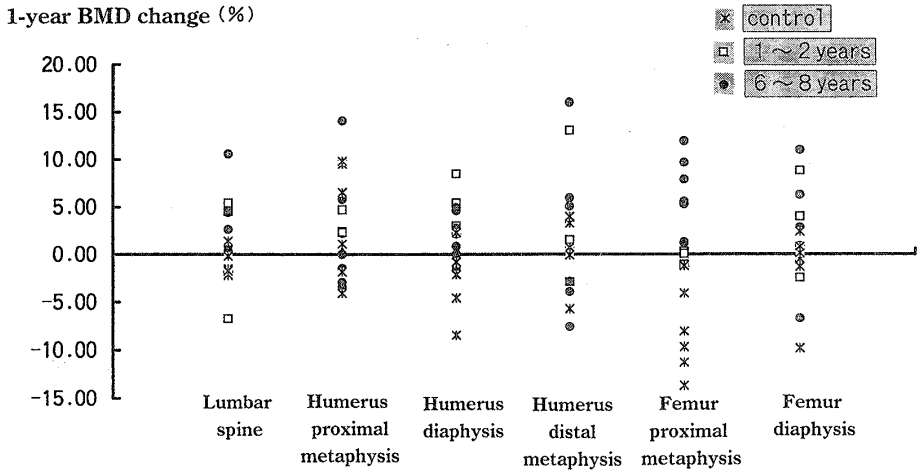

Fig. 4. Change in 1 year of BMD values for sumo wrestlers

Wrestlers with 1-2 years of experience show increased BMD in each part of the humerus and in the femur diaphysis, but no change in the femur proximal metaphysis. On the other hand, all wrestlers with 6-8 years of experience show increased BMD of the lumbar spine and femur proximal metaphysis.

Table 4. Nutritional status of the sumo wrestlers and controls

Sumo wrestlers: energy and nutrient intake (average of 2 days)

	Energy (kcal)	Protein (g)	Lipid (g)	Carb. (g)	Fiber (g)	Calcium (mg)	Iron (mg)	V. A (IU)	V. B1 (mg)	V. B2 (mg)	V. C (mg)	Salt (g)
Midday meal	2,440	86.9	58.5	355.3	4.6	375	12.3	1,501	0.74	1.06	59	18.3
Evening meal	1,499	70.2	66.3	137.8	2.0	155	9.5	2,623	0.57	0.93	36	7.5
Total/day	3,939	157.1	123.4	493.1	6.6	529	21.8	2,812	1.30	1.98	94	25.8
20s male*												
Level IV	4,000	115.0				750	10.0	2,000	1.60	2.20	50	10.0

*Dietary allowance for a heavy level (IV) of physical activity for males in their 20s (height: 185 cm). The intakes of calcium, V. B1 and V. B2 were slightly insufficient, but the PFC ratio (ratio of protein, fat, or carbohydrate to total energy) was 16.0% for protein, 28.2% for fat, and 55.8% for carbohydrate, showing good nutritional balance.

Controls ($N=12$)

	Energy (kcal)	Protein (g)	Lipid (g)	Carb. (g)	Fiber (g)	Calcium (mg)	Iron (mg)	V. A (IU)	V. B1 (mg)	V. B2 (mg)	V. C (mg)	Salt (g)
Average/day	1,981	68.7	63.7	250.2	12.0	367	8.1	1,429	0.86	1.15	65	8.1
SD	341	12.1	15.6	45.2	2.4	138	1.8	524	0.18	0.30	48	1.9
RDA**	2,285	73.0				630	10.0	2,000	0.93	1.28	50	10.0

**Recommended dietary allowance for these subjects. Intakes of most nutrients were insufficient. In particular, the calcium intake was less than 60% of the recommended daily allowance.

metaphysis and the femur diaphysis were correlated with such physical characteristics as body weight and exercise.

However, as shown in Fig. 3, no such significant correlation was observed between BMD values in the femur proximal metaphysis and many physical factors in this study. Therefore, it is speculated, stamping, an exercise and training specific to sumo, rather than physical characteristics such as body weight may have an effect on the femur proximal metaphysis.

The evaluation in Fig. 4 of annual changes in BMD in the sumo wrestlers shows an increase in the diaphysis of the humerus and femur, but no changes in BMD of the femur proximal metaphysis of wrestlers with 1-2 years of experience.

Animal studies by Raab *et al.*[15] and Katsuta and Shimegi[16] have clarified the effects of exercise on cortical bone. Shimegi *et al.*[17] have reported a significantly higher total bone area and cortical bone area of the femur in male runners than in controls. In wrestlers with 1-2 years of experience, the diaphysis, which primarily consists of cortical bone, may have been more markedly affected by exercise. On the other hand, in wrestlers with 6-8 years of experience, BMD of the femur proximal metaphysis was markedly increased. These findings suggest that cumulative stamping, a practice and training specific to sumo, affected BMD of the femur proximal metaphysis. However, further studies are necessary on the detailed mechanism for sumo-specific exercise itself and its effects on bones. BMD increased during 1 year in each part, except the femur proximal metaphysis, in those wrestlers with 1-2 years of experience. Our dietary survey (Table 4) shows a slightly inadequate calcium intake by the wrestlers. However, ingested or absorbed calcium may be more effectively utilized by the daily push-against practice and stamping in sumo. Compared with the appropriate PFC ratio[18] (protein, 12-13%; fat, 20-30%; and carbohydrate, 57-68%), the diet of sumo wrestlers was well balanced. On the other hand, in the controls, the intake of most nutrients including energy was insufficient. In addition to the calcium intake insufficiency, the balance of nutrient intake was poor, and the subjects had no exercise habits. These findings may have affected BMD of each bone part. BMD of the lumbar spine in the controls was 94.8% of the standard value for age-matched male Japanese.

To increase the strength of skeletal muscles and BMD in sumo wrestlers, maintaining body weight, adequate practice, and an appropriate intake of each nutrient such as calcium in the daily diet are all necessary. In addition, it is important as part of the health management of each sumo wrestler for him to know his own BMD and to be aware of his diet. This may also greatly contribute to general health management in the stable.

CONCLUSION

The effects of special physical characteristics and exercise on BMD in sumo wrestlers were investigated for 1 year. The sumo wrestlers, who have special physical characteristics and do a great deal of practice, showed BMD relatively high values for the diaphysis of the humerus and femur and for the proximal metaphysis of the femur. It is suggested from these study results that not only the increase in physique, but also stamping in the ring, an exercise specific to sumo, and a well balanced diet may all contribute to the increased BMD of each bone part.

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力士の骨密度に関する検討

塚原典子，麻見直美，江澤郁子

（日本女子大学家政学部）

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日本の国技である相撲の世界は，特殊な食生活形態および身体的特徴を有し，さらに稽古量も多いことから，これらが骨に与える影響は大きいと考えられる．そこで本研究では相撲界における，体格，日常の食生活および身体活動状況等が骨密度に及ぼす影響について経時的観察（1年間）を実施し，さらに，同年代の一般男子学生の骨密度との比較検討も併せて行った．その結果，力士の骨密度は，一般男子学生に比べ，いずれの部位においても有意な高値（$p<0.001$）を示した．また，力士の番付けと体格の間に関係が認められたことからも，力士にとって体格を増進し，骨格筋等の筋力アップとそれに伴う骨の強化は，最も重要な課題であると考えられる．また，入門1～2年の力士で，1年間で上腕骨および大腿骨の骨幹部の骨密度の増加が認められたことから，骨幹部は体重や稽古（荷重やメカニカルストレス）の影響を受けやすい部位である可能性が考えられる．さらに，入門歴6～8年の力士において大腿骨近位部骨密度の増加が認められたことからも，しこを踏むという相撲独特の運動（稽古）が各部位の骨密度を高めるものと思われる．

キーワード：二重エネルギー骨密度測定，骨密度，腰椎，上腕骨，大腿骨，力士．