北京航空航天大学四年级博士生和五年级直博生
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	Analysis of Bone Mineral Density/Content of Paratroopers and Hoopsters		4	2018.05.20	Journal of Healthcare Engineering	1-SCI 源
	高冲击运动时不同着陆姿势对骨密度和骨矿含量的影响		4	2018.04	医用生物力学	11-CSCD 源
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	一种带有缓冲鞋垫的足部外置护具		5	2016.05.04	CN105533853A	1-发明专利
	半刚性腰部护具		4	2017.07.28	CN106984030A	1-发明专利
	运动性疲劳智能检测与分析系统		6	2017.11.24	201711187362.6	1-发明专利
	非线性梯度生物力学特征的运动贴布		5	2017.10.12	201710945778.3	1-发明专利
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Research Article

Analysis of Bone Mineral Density/Content of Paratroopers and Hoopsters

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The different mechanical stimulus affects the bone mass and bone strength. The aim of this study was to investigate the effect of landing posture of the hoopster and paratrooper on the bone mass. In this study, 39 male participants were recruited including 13 paratroopers, 13 hoopsters, and 13 common students (control groups). Bone area (BA), BMD and BMC of calcaneus, and 1–5th of the metatarsus, hip, and lumbar spine (L_1–L_4) were measured by the dual-energy X-ray absorptiometry. Also, the vertical ground reaction forces (GRFs) of hoopsters and paratroopers were measured by the landing of 1.2 m 3D force platform. BA of hoopsters at the calcaneus, lumbar spine, and hip were significantly higher than the control group. The lumbar spine, hip, calcaneus, the 1st and 2nd metatarsals, BMC of paratroopers, and control groups were significantly lower than hoopsters. BMD of the lumbar spine, hip, and right and left femoral necks in hoopsters were significantly higher than the other participants. BMC and BMD of lower limber showed no significant difference between paratroopers and the control group. Besides, peak GRFs of paratroopers (11.06 times of BW) were significantly higher than hoopsters (6.49 times of BW). The higher GRF in the landing train is not always in accordance with higher BMD and BMC. Variable loads in hoopsters can improve bone remodeling and play an important role in bone expansions for trabecular bones. This will be considered by the method of training to prevent bone loss.

1. Introduction

Low bone mass, as one of the important factors for osteoporotic fractures, is usually measured with bone mineral content (BMC) and bone mineral density (BMD) [1]. Calcium deficiency, inadequate vitamin D intake, excessive drinking, low reproductive hormone levels, and lack of physical activity are main potential factors of bone loss [2, 3]. It was reported that physical exercise was usually a benefit to increase the bone mass and promote skeletal development [4]. Different loads contribute to bone formation and maintenance of bone metabolism, which also would improve the bone strength or microarchitecture [1, 5, 6]. The mechanical loads of the adult rats showed the difference of intermittent and normal exercises [7].

The cyclic load on bones is generated in different exercises [8]. It was reported that BMD could be increased by duration exercise of more than two hours per week [9]. It was also found that the 2% BMD of the femoral neck was improved by the impact of exercise done for 6 months [10]. Continuous mechanical stimulus helps to maintain bone mass that is important to improve BMD and BMC [11–13]. Osteogenic responses are always produced at the specific loading sites [14, 15]. Basketball, volleyball, and gymnastics from the three times body weight (BW) or greater of reaction force are defined as high-impact exercises [16]. It was beneficial to bone remodeling in high-impact exercises [17]. It was also shown that those high-impact exercises increased BMD and BMC of prepubertal girls [18]. BMD of the total body, lumbar spine (LS), femoral neck (FN), legs, and arms would be increased due to high-impact exercises such as basketball and volleyball exercise [14]. BMC and BMD of the lower limbs were not increased in no-impact or low-impact exercises (cycling and swimming) [19, 20], and there may be not enough stimuli against bones [17].

Basketball exercise included the various postures such as running, starts, stops, and shuffling. The multidirectional loads were produced during exercise. Basketball sport involves mainly jumping and landing [21]. They lean forward with the forefoot landing on the ground first, followed by the whole foot [22]. The twisting movement of the feet was found in balance training in basketball sport [23]. The triceps surae muscle in the musculoskeletal system mainly maintains the stability of ankle joints [24]. The ground reaction forces (GRFs) during the vertical jump-landing were generated in basketball exercise [25]. Meanwhile, parachuting was also a typical high-impact action [26]. Paratroopers perform half-squat parachute landing and keep their feet parallel to ground in the landing process [27]. Dynamic postures of hoopsters and paratroopers were quite different during the landing process. The mechanical loads acting on bones were also different. The effect of different dynamic landing postures on osteogenic responses still needs the quantified research method. In this study, BMD and BMC of hoopsters and paratroopers were investigated by the instruments and experiments, respectively. It would provide suggestion of training methods to prevent bone loss and osteoporotic fracture.

2. Methods

Thirty-nine males aged 20–25 years participated in this study (13 paratroopers, 13 hoopsters, and 13 normal men with less involvement in sports as the control group). They were divided into two subgroups: subgroup I with men 20–22 years old including 7 paratroopers, 7 hoopsters, and 7 controls, and the others were subgroup II aged 23–25 years. Volunteers were from the air force base, basketball sports team, and students in university, respectively. Paratroopers and hoopsters participated in training for more than 10 hours weekly compared to less than 1 hour of controls. Height, weight, and body mass index (BMI) of volunteers were shown in Table 1. Each volunteer has no disease of musculoskeletal disorders and bone metabolism.

Bone area (BA, cm^2), BMD (g/cm^2), and BMC (g) of the calcaneus, the 1st to the 5th metatarsus, hip (left hip and right hip), and lumbar spine (L_1–L_4) were measured by dual-energy X-ray absorptiometry (DXA), respectively. The calcaneus and the metatarsus were placed at 90° inversion and 45° eversion by horizontal scanning of DXA, respectively. The informed consent including the measurement method and the potential risk were signed by volunteers. All measurements were performed in the same condition from March to May, 2016.

The statistical data of three groups (paratroopers, hoopsters, and controls) were compared by the one-way ANOVA test and nonparametric test. The significant differences of BA, BMC, and BMD are shown in Table 1.

Table 1: Characteristics of participations.

Variables	Paratroopers^{a}	Hoopsters^{b}	Controls^{c}
Subgroup I			
Height (cm)	179.83 ± 4.02	$184.29 \pm 4.11^{a,c}$	173.00 ± 6.73
Weight (kg)	70.03 ± 6.32	75.71 ± 8.01	70.66 ± 11.10
BMI ($kg \cdot m^{-2}$)	21.83 ± 1.99	22.29 ± 1.62	23.34 ± 2.68
Subgroup II			
Height (cm)	174.1 ± 3.70	$181.17 \pm 8.13^{a,c}$	173.83 ± 2.14
Weight (kg)	68.72 ± 4.80	76.33 ± 8.45	64.33 ± 3.08
BMI ($kg \cdot m^{-2}$)	22.62 ± 2.32	23.18 ± 1.280	21.32 ± 1.23

Note. Data are means ± SD; ^{a}significantly different with paratroopers, $P < 0.05$; ^{b}significantly different with hoopsters, $P < 0.05$; ^{c}significantly different with controls, $P < 0.05$.

Besides, hoopsters and paratroopers were required to jump from a 1.2 m platform. The height was is consistent with the velocity of about 6 m/s of paratroopers landing [28]. Landing postures of hoopsters and paratroopers were captured by vidicon (Figures 1 and 2). The GRF was measured by a 3D force platform (1000 Hz, SMA-6, AMTI, USA).

3. Results

BA of the calcaneus, metatarsus, hip, femoral neck, and lumbar spine in both groups is shown in Tables 2 and 3. It was found that BA of the calcaneus in hoopsters was significantly larger than controls ($P < 0.05$). The difference of the metatarsal BA among hoopsters, paratroops, and controls was less obvious. In subgroup I, BA of the lumbar spine and hip in hoopsters was significantly greater than controls ($P < 0.01$). Except for the BA of the left and right femoral neck and the fifth metatarsal, hoopsters were significantly greater than paratroopers ($P < 0.01$)

BMC values of the different bones in hoopsters, paratroopers and controls are listed in Tables 4 and 5. BMC of hoopsters' calcaneus and the 1st and 2nd metatarsals was significantly higher than that of paratroopers ($P < 0.05$) and controls ($P < 0.01$). BMC of hoopsters was also significantly higher than controls and paratroopers ($P < 0.05$) at the lumbar spine (L_1, L_2, L_3, L_4, and total lumbar spine) except for L_3 in subgroup II. BMC of hoopsters' total hip was the highest compared with controls and paratroopers ($P < 0.05$). However, there was no significant difference among all participants in BMC of the femoral neck.

BMD of the calcaneus in hoopsters was significantly higher than controls ($P < 0.05$) in both groups as shown in Tables 6 and 7. BMD of the first, second, and third metatarsals in hoopsters was significantly greater than controls ($P < 0.05$) in subgroup I. BMD of the third, fourth, and fifth metatarsals in paratroopers was significantly higher than controls ($P < 0.05$) in subgroup II. Higher BMD of the lumbar spine, hip, and femoral neck in hoopsters was obtained statistically compared to other bones ($P < 0.01$). However, paratroopers and controls had no significant difference in BMD at those anatomical locations.

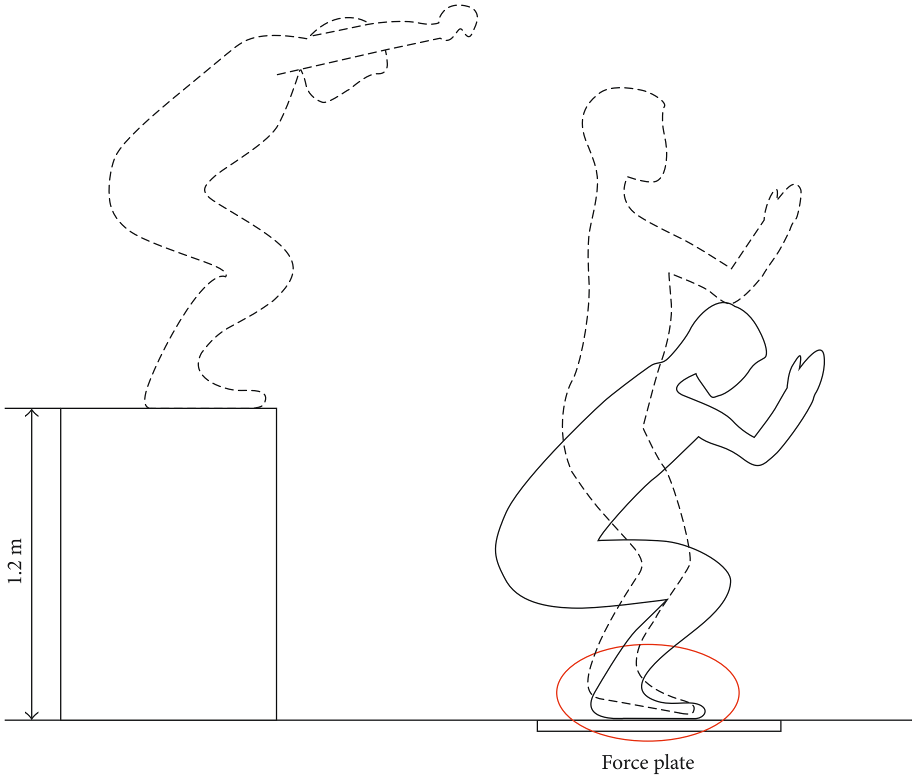

Figure 1: Landing posture of hoopsters.

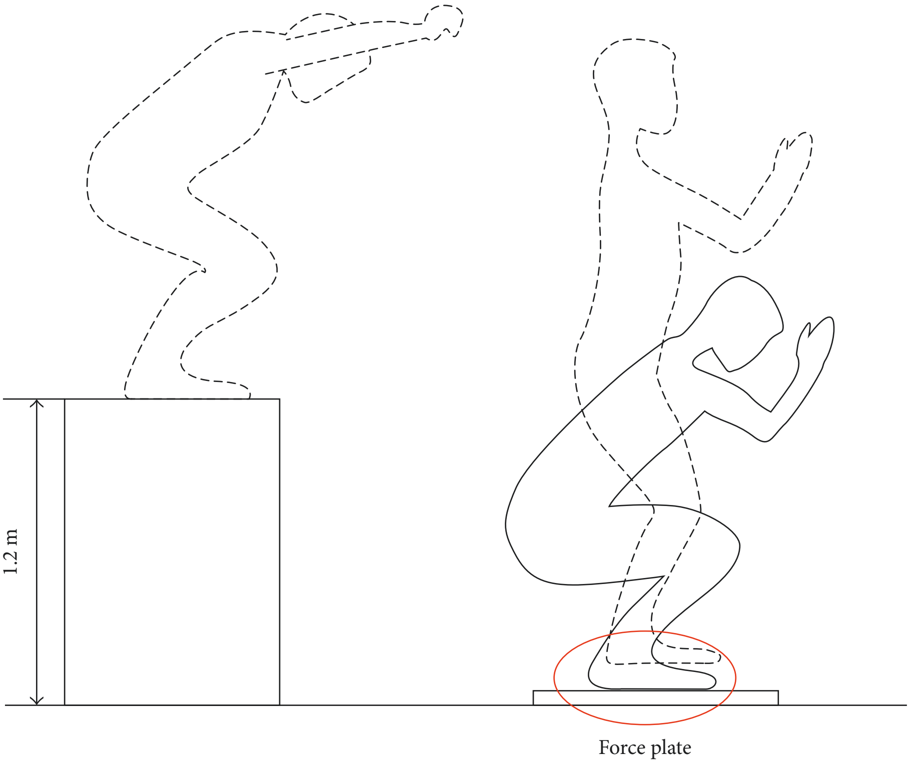

Figure 2: Landing posture of paratroopers.

Table 2: BA (cm^2) of the different anatomical locations in subgroup I.

Variables	Paratroopers^{a} ($n = 7$)	Hoopsters^{b} ($n = 7$)	Controls^{c} ($n = 7$)
Calcaneus	34.49 ± 3.83	36.66 ± 2.61^{c}	31.26 ± 3.32
First metatarsal	12.78 ± 0.88	13.54 ± 1.41	11.46 ± 0.74
Second metatarsal	8.37 ± 0.94	9.04 ± 1.28^{c}	7.76 ± 0.85
Third metatarsal	7.79 ± 1.13	8.27 ± 0.98	7.30 ± 0.70
Fourth metatarsal	7.95 ± 0.83	8.41 ± 1.15	7.42 ± 0.87
Fifth metatarsal	10.85 ± 1.14	10.24 ± 1.35	9.73 ± 1.28
Lumbar spine (L_1–L_4) L_1	13.97 ± 1.70	$16.43 \pm 1.05^{a,c}$	13.96 ± 0.83
L_2	15.39 ± 0.10	$17.50 \pm 2.06^{a,c}$	14.84 ± 1.17
L_3	17.16 ± 1.31	19.09 ± 2.74^{c}	16.54 ± 1.31
L_4	18.67 ± 1.15	$22.54 \pm 2.39^{a,c}$	18.17 ± 2.15
L_{total}	65.19 ± 4.40	$75.56 \pm 7.56^{a,c}$	63.51 ± 4.52
Left femoral neck	6.10 ± 1.50	5.64 ± 0.38	5.64 ± 0.37
Left hip	40.78 ± 3.35	$47.11 \pm 4.14^{a,c}$	39.64 ± 3.77
Right femoral neck	$6.77 \pm 1.30^{b,c}$	5.46 ± 0.42	5.45 ± 0.43
Right hip	42.79 ± 3.0	46.53 ± 3.95^{c}	38.46 ± 4.89

Note. Data are means ± SD; ^{a}significantly different with paratroopers, $P < 0.05$; ^{b}significantly different with hoopsters, $P < 0.05$; ^{c}significantly different with controls, $P < 0.05$.

Table 3: BA (cm^2) of the different anatomical locations in subgroup II.

Variables	Paratroopers^{a} ($n = 6$)	Hoopsters^{b} ($n = 6$)	Controls^{c} ($n = 6$)
Calcaneus	32.00 ± 2.79	$37.50 \pm 4.71^{a,c}$	31.95 ± 2.85
First metatarsal	12.59 ± 1.58	13.40 ± 2.88	11.55 ± 1.46
Second metatarsal	8.30 ± 0.81	8.86 ± 1.06	8.11 ± 0.51
Third metatarsal	6.91 ± 0.69	7.93 ± 1.10	7.22 ± 0.44
Fourth metatarsal	7.08 ± 0.49	7.94 ± 0.48	7.42 ± 0.77
Fifth metatarsal	9.54 ± 0.48	10.57 ± 1.01	9.17 ± 1.08
Lumbar spine (L_1–L_4) L_1	14.19 ± 0.95	15.38 ± 1.43	14.26 ± 1.19
L_2	15.16 ± 1.18	16.36 ± 1.48	15.32 ± 0.49
L_3	17.17 ± 2.12	18.12 ± 1.52	16.27 ± 1.63
L_4	18.10 ± 0.98	19.78 ± 2.00^{a}	18.30 ± 0.63
L_{total}	64.61 ± 4.83	69.64 ± 6.27	64.15 ± 3.18
Left femoral neck	5.15 ± 1.32	5.27 ± 1.17	5.35 ± 0.26
Left hip	41.21 ± 4.19	44.07 ± 4.28	40.72 ± 2.17
Right femoral neck	5.21 ± 1.14	5.78 ± 0.76	4.99 ± 0.46
Right hip	41.57 ± 3.03	45.03 ± 4.12	40.91 ± 3.26

Note. Data are means ± SD; ^{a}significantly different with paratroopers, $P < 0.05$; ^{b}significantly different with hoopsters, $P < 0.05$; ^{c}significantly different with controls, $P < 0.05$.

Table 4: BMC (g) of the different anatomical locations in subgroup I.

	Paratroopers^{a} ($n = 7$)	Hoopsters^{b} ($n = 7$)	Controls^{c} ($n = 7$)
Calcaneus	27.84 ± 3.89	$32.52 \pm 5.12^{a,c}$	24.58 ± 2.64
First metatarsal	6.19 ± 0.85	$8.01 \pm 1.84^{a,c}$	5.68 ± 0.78
Second metatarsal	3.54 ± 0.36	$4.60 \pm 0.84^{a,c}$	3.15 ± 0.58
Third metatarsal	3.09 ± 0.38	3.61 ± 1.15^{c}	2.41 ± 0.38
Fourth metatarsal	2.90 ± 0.60	2.96 ± 0.79	2.26 ± 0.48
Fifth metatarsal	3.82 ± 0.86	3.59 ± 0.81	3.06 ± 0.73
Lumbar spine (L_1–L_4) L_1	13.34 ± 1.68	$17.29 \pm 1.31^{a,c}$	13.13 ± 1.87
L_2	15.43 ± 1.43	$19.70 \pm 2.06^{a,c}$	15.08 ± 2.52
L_3	17.79 ± 1.48	$23.03 \pm 3.34^{a,c}$	17.56 ± 2.26
L_4	19.19 ± 0.93	$25.31 \pm 2.31^{a,c}$	19.42 ± 2.49
L_{total}	65.75 ± 5.16	$85.33 \pm 8.38^{a,c}$	65.19 ± 8.55
Left femoral neck	5.84 ± 1.33	6.86 ± 0.92	5.41 ± 0.78
Left hip	40.51 ± 5.09	$58.94 \pm 5.05^{a,c}$	41.62 ± 3.00
Right femoral neck	6.46 ± 1.34	6.72 ± 0.72	5.18 ± 0.67^{b}
Right hip	41.96 ± 4.35	$57.45 \pm 4.61^{a,c}$	40.36 ± 5.76

Note. Data are means ± SD; ^{a}significantly different with paratroopers, $P < 0.05$; ^{b}significantly different with hoopsters, $P < 0.05$; ^{c}significantly different with controls, $P < 0.05$.

Table 5: BMC (g) of the different anatomical locations in subgroup II.

Variables	Paratroopers^{a} ($n = 6$)	Hoopsters^{b} ($n = 6$)	Controls^{c} ($n = 6$)
Calcaneus	23.85 ± 2.98	$32.95 \pm 9.03^{a,c}$	22.82 ± 3.15
First metatarsal	6.46 ± 0.81	$7.59 \pm 1.88^{a,c}$	5.64 ± 0.93
Second metatarsal	3.55 ± 0.43	$4.22 \pm 0.73^{a,c}$	3.34 ± 0.36
Third metatarsal	2.67 ± 0.50	2.61 ± 0.88	2.17 ± 0.96
Fourth metatarsal	2.65 ± 0.39^{c}	2.50 ± 0.64	2.01 ± 0.29
Fifth metatarsal	3.43 ± 0.55	3.51 ± 0.89	2.57 ± 0.47
Lumbar spine (L_1–L_4) L_1	14.19 ± 1.06	$17.20 \pm 2.97^{a,c}$	12.49 ± 1.47
L_2	15.74 ± 1.02	$19.84 \pm 3.83^{a,c}$	14.02 ± 1.01
L_3	18.93 ± 2.27	22.50 ± 4.24^{c}	$14.88 \pm 1.95^{a,b}$
L_4	19.16 ± 2.57	$23.70 \pm 4.22^{a,c}$	16.09 ± 1.45
L_{total}	68.02 ± 6.46	$83.24 \pm 14.95^{a,c}$	57.47 ± 4.81
Left femoral neck	4.89 ± 1.73	6.29 ± 1.94	4.51 ± 0.67
Left hip	40.86 ± 7.54	$53.28 \pm 7.56^{a,c}$	38.67 ± 5.12
Right femoral neck	5.36 ± 1.63	6.73 ± 1.51^{c}	4.14 ± 0.39
Right hip	42.96 ± 7.42	$53.68 \pm 7.50^{a,c}$	38.44 ± 4.88

Note. Data are means ± SD; ^{a}significantly different with paratroopers, $P < 0.05$; ^{b}significantly different with hoopsters, $P < 0.05$; ^{c}significantly different with controls, $P < 0.05$.

Table 6: BMD (g/cm^2) of the different anatomical locations in subgroup I.

Variables	Paratroopers^{a} ($n = 7$)	Hoopsters^{b} ($n = 7$)	Controls^{c} ($n = 7$)
Calcaneus	0.81 ± 0.94	0.88 ± 0.92^{c}	0.79 ± 0.48
First metatarsal	0.49 ± 0.66	$0.59 \pm 0.85^{a,c}$	0.50 ± 0.57
Second metatarsal	0.43 ± 0.44	0.51 ± 0.64^{c}	0.40 ± 0.47
Third metatarsal	0.40 ± 0.75	0.43 ± 0.95^{c}	0.33 ± 0.33
Fourth metatarsal	0.37 ± 0.08	0.35 ± 0.05	0.30 ± 0.05
Fifth metatarsal	0.36 ± 0.09	0.35 ± 0.04	0.31 ± 0.05
Lumbar spine (L_1–L_4) L_1	0.96 ± 0.04	1.05 ± 0.05	0.94 ± 0.10
L_2	1.00 ± 0.05	1.13 ± 0.03	1.01 ± 0.10
L_3	1.04 ± 0.06	$1.21 \pm 0.04^{a,c}$	1.06 ± 0.10
L_4	1.03 ± 0.04	1.13 ± 0.09	1.07 ± 0.06
L_{total}	1.01 ± 0.04	$1.13 \pm 0.04^{a,c}$	1.02 ± 0.08
Left femoral neck	0.96 ± 0.08	$1.21 \pm 0.13^{a,c}$	0.96 ± 0.10
Left hip	0.99 ± 0.08	$1.25 \pm 0.09^{a,c}$	1.05 ± 0.09
Right femoral neck	0.95 ± 0.11	$1.23 \pm 0.08^{a,c}$	0.95 ± 0.09
Right hip	0.98 ± 0.08	$1.24 \pm 0.07^{a,c}$	1.05 ± 0.07

Note. Data are means ± SD; ^{a}significantly different with paratroopers, $P < 0.05$; ^{b}significantly different with hoopsters, $P < 0.05$; ^{c}significantly different with controls, $P < 0.05$.

Table 7: BMD (g/cm^2) of the different anatomical locations in subgroup II.

Variables	Paratroopers^{a} ($n = 6$)	Hoopsters^{b} ($n = 6$)	Controls^{c} ($n = 6$)
Calcaneus	0.75 ± 0.13	0.87 ± 0.14^{c}	0.71 ± 0.07
First metatarsal	0.52 ± 0.09	0.56 ± 0.03^{c}	0.49 ± 0.05
Second metatarsal	0.43 ± 0.08	0.47 ± 0.04	0.41 ± 0.02
Third metatarsal	0.39 ± 0.07	0.33 ± 0.08	0.30 ± 0.01^{a}
Fourth metatarsal	0.38 ± 0.06	0.31 ± 0.07	0.27 ± 0.03^{a}
Fifth metatarsal	0.36 ± 0.07	0.33 ± 0.07	0.28 ± 0.03^{a}
Lumbar spine (L_1–L_4) L_1	1.00 ± 0.08	1.11 ± 0.12	0.88 ± 0.07
L_2	1.04 ± 0.11	$1.20 \pm 0.15^{a,c}$	0.91 ± 0.04
L_3	1.11 ± 0.13	1.23 ± 0.15	0.91 ± 0.06
L_4	1.06 ± 0.15	1.19 ± 0.11	0.88 ± 0.08
L_{total}	1.06 ± 0.12	$1.19 \pm 0.13^{a,c}$	0.90 ± 0.05
Left femoral neck	0.94 ± 0.15	$1.18 \pm 0.15^{a,c}$	0.85 ± 0.14
Left hip	0.99 ± 0.14	$1.21 \pm 0.10^{a,c}$	0.95 ± 0.10
Right femoral neck	1.02 ± 0.18	$1.16 \pm 0.15^{a,c}$	0.84 ± 0.10
Right hip	1.03 ± 0.17	$1.19 \pm 0.09^{a,c}$	0.94 ± 0.08

Note. Data are means ± SD; ^{a}significantly different with paratroopers, $P < 0.05$; ^{b}significantly different with hoopsters, $P < 0.05$; ^{c}significantly different with controls, $P < 0.05$.

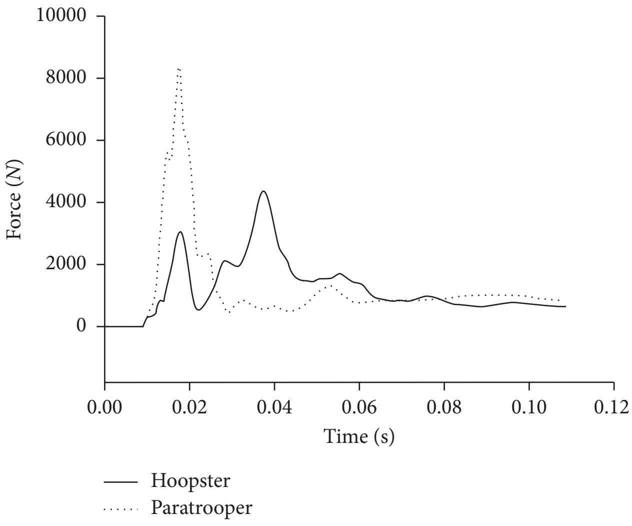

Figure 3: The vertical GRF of hoopsters and paratroopers.

Besides, peak vertical GRFs of paratroopers were 11.06 times of BW (SD ± 0.96) compared to 6.49 times of BW in hoopsters (SD ± 1.19). Compared with the forefoot of hoopsters, which first lands on the ground following the whole foot (Figure 1), the landing posture of paratroopers kept the feet parallel to ground (Figure 2). At the same time, the vertical GRF of both groups are shown in Figure 3. Only one peak value in paratroopers was obtained compared to two peaks of hoopsters.

4. Discussion

It was reported that different types of impact exercises including basketball, volleyball, swimming, gymnastics, handball, running, and cycling sports had different effects on BMC and BMD [11, 16, 17]. Basketball sport as a high-impact exercise had positive effect on BMC and BMD [29]. High ground reaction forces were also generated in half-squat parachute landing [26]. Paratroopers kept their feet parallel to ground in the landing process [27]. However, the landing posture of hoopsters was first landing on ground with forefoot, following the whole feet to jump [25]. Dynamic postures of hoopsters and paratroopers were quite different in the landing process. However, the effect of different dynamic landing postures on osteogenic responses still needs the quantified research method. So, the hoopsters and paratroopers as the typical impact subjects were recruited for landing postures to investigate BMD and BMC.

In this study, BMC of the first and second metatarsals in hoopsters was significantly higher than controls. This was consistent with studies that basketball exercising could enhance BMC of the bones [30]. Paratroopers in China perform half-squat parachute landing and keep their feet parallel to ground [27]. Compared with only a peak value of the paratrooper during landing, it was found that the first peak value of GRF was obtained during forefoot of the hoopster first landing on the ground, following the second peak value of the whole feet against ground (Figure 3). It indicated that in daily exercising, jumping of hoopsters with two vertical GRF peaks more effectively generated mechanical loadings at the metatarsals than paratroopers, and this mechanical stimulus would promote local osteogenic responses at loading sites [14, 15]. Thus, land of hoopsters compared to paratroopers will improve BMC of the forefoot after frequent mechanical stimulus. However, it was further proof whether the higher BMC could help paratroopers to reduce injury.

BMC and BMD of the calcaneus and total hip in hoopsters were improved in contrast to controls in our study. It was consistent with previous study that BMC and BMD of the leg, hip, and pelvis were higher than controls [17]. Weight-bearing and high-impact exercises could stimulate bone mineral acquisition in children and adolescents [18, 31]. However, BMC and BMD of the calcaneus and total hip in paratroopers were not sensitive to daily training. It was found that training time of paratroopers in the questionnaire was about 40 to 50 hours weekly, which nearly included 70% of time for landing training. The peak GRF of paratroopers was nearly twice of hoopsters. In our study, it was clear that the high-impact exercising helped with bone formation and enhanced BMD [32]. The effect of the exercise posture on BMD and BMC has the different values for hoopsters' and paratroopers' bones. In Frost's mechanic stability theory, bone mass and bone strengthen were improved with the normal exercise [33]. The peak GRF of paratroopers was about 11 times of BW which would produce excessively large impact force. However, the cyclic loading from basketball exercising may be beneficial to increase BMC and BMD.

Waener et al. [34] found that BMD of all the bones in cyclists, mountain cyclists, was significantly higher. It was shown that the mountain cyclists had varying intensities and frequencies to stimulate osteogenic formation. Similarly, BMD of total lumbar spine and total hip in hoopsters were significantly higher than paratroopers. This was in accordance with the study that the variable velocities in basketball exercising could improve the bone mass and bone strength [22]. Thus, tension, compression, shear, and bending produced at different strain stimulus would act on lumbar spine and hip, which would induce bone formation and enhance BMD at weight-bearing regions [29, 32, 35]. It was also certified that the varying loads could be more benefit to positive osteogenic formation than constant loads [36, 37]. Thus, BMD of the lumbar spine and hip in basketball exercising was higher compared with parachuting. This was in accordance with the study by Platen et al. [38].

BA of the calcaneus, total lumbar spine, and total hip in hoopsters was also significantly higher than controls. This finding was consistent with previous conclusion that the basketball exercising enhanced BA of weight-bearing bones [29]. The BA of the left, right femoral necks and metatarsals in hoopsters was changed mildly compared to controls. It was shown that the mechanical stress of the cortical bone was less sensitive than the trabecular bone [39]. Besides, BA of paratroopers had no promotion compared with controls at measured anatomical locations. Although training of paratroopers was high-impact exercising, it could not generate bone expansions at loaded bones [40]. Different exercise modalities induce variable mechanical stress at stimulated regions [41]. The different BA between paratroopers and hoopsters was caused from the different landing postures.

This study had several limitations. Firstly, the number of paratroopers was limited by air force base. Secondly, there was no dietary information, which may affect bone composition. Thirdly, lean tissue mass and degree of physical fitness were not considered due to the diffcult quantitative methods.

5. Conclusions

The high-impact exercises have positive effect on osteogenic formation. BMC and BMD are not in accordance with magnitude of GRF. In this study, basketball exercise from the variable loads may be more effectively increasing BMC and BMD than parachuting with constant loads at loaded sites. Exercising like basketball with high acceleration and multidimensional directions needs further study on its positive effects of bone strength and prevention of osteoporotic fracture caused by bone loss.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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[发明公布] 一种带有缓冲鞋垫的足部外置护具

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分类号：A41D13/06(2006.01)I

摘要： 本发明提供了一种带有缓冲鞋垫的足部外置护具。所述护具包括刚性护踝和缓冲鞋垫两部分，刚性护踝采用低温热塑板成型得到，左右保护板与缓冲鞋垫、刚性护踝底板采用螺钉连接,可以绕螺钉转动,松紧通过前方板的三条固定带或后面鞋带调节；与刚性护踝连接的缓冲鞋垫由3层构 全部

【发明专利申请】 *事务数据*

[发明公布] 半刚性腰部护具

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分类号：A63B71/12(2006.01)I 全部

摘要： 本发明公开一种半刚性腰部护具，包括第一护腰本体和第二护腰本体，两个护腰本体经弹性带固定连接，两个护腰本体上对应背部的位置分别设置刚性弹簧片，刚性弹簧片的曲率与背部弯曲时的曲率一致；两个护腰本体由橡胶、锦纶、弹力纤维材料制成，两个护腰本体对应背部位置的弹力纤维材料，沿背部肌肉纤维的走向编织。本发明的半刚性腰部护具，弹性佳、舒适性佳、透气性好、穿戴方便，在体育运动或跳伞等极限运动过程中，可有效限制腰部的过度前屈，有效防护运动者落地时腰部免受损伤。 收起

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高冲击运动时不同着陆姿势对骨密度和骨矿含量的影响

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摘要: **目的** 研究不同类型高冲击运动对于骨密度(bone mineral density, BMD)和骨矿含量(bone mineral content, BMC)的影响。**方法** 招募39名志愿者，其中伞兵、篮球运动员和作为对照组的普通大学生各13名，将其分成两组(第1组:20~22岁;第2组:23~25岁)，分别测量跟骨、第1~5跖骨、髋关节和腰椎(L1~4)BMD和BMC。**结果** 篮球运动员跟骨、第1、2跖骨、总腰椎和髋部BMC显著大于伞兵和对照组;篮球运动员在腰椎、髋关节和股骨颈处BMD也显著大于其他组;伞兵和对照组在测量部位的BMD和BMC无显著性差异。**结论** BMC与BMD并非总是正比于平时运动时的垂直地面反作用力。相比跳伞训练，篮球运动能更好提高BMC和BMD，这种变载荷运动作为训练方法，更有利于降低骨质疏松性骨折的风险。

关键词: 高冲击运动; 跳伞; 篮球; 骨密度; 骨矿含量; 变载荷
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Effects of Different Landing Postures on Bone Mineral Density and Content during High-Impact Exercises

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Abstract: **Objective** To study effects of different types of high-impact exercises on the increment of bone mineral density (BMD) and bone mineral content (BMC). **Methods** Thirty-nine male volunteers, including 13 hoopsters, 13 paratroopers, and 13 common college students as the control, were recruited and divided into two subgroups (subgroup 1: 20-22 years old; subgroup 2: 23-25 years old). Their BMDs and BMCs on calcaneus, first through fifth metatarsus, hip, and lumbar spine (L1-4) were evaluated. **Results** The BMC of calcaneus, the first and second metatarsals, total lumbar spine, and total hip in the hoopster group was significantly higher than that in the control group and paratrooper group. The hoopster group obtained statistically higher BMD at the lumbar spine, hip, and femoral neck than the other two groups. However, the BMCs and BMDs of the paratrooper

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group and control group had no significant differences at almost all measured anatomical locations. **Conclusions** BMC and BMD are not always in positive correlation with vertical ground reaction forces during normal exercises. Compared with parachuting training, playing basketball as a kind of variable load exercise can effectively increase BMC and BMD, and is more beneficial for reducing the risk of osteoporotic fracture.

Key words: high-impact exercises; parachute; basketball; bone mineral density (BMD); bone mineral content (BMC); variable loads

低骨量是导致骨质疏松性骨折的重要因素。引起骨质流失的原因有很多，缺钙、维生素 D 摄入不足、过度饮酒、生殖激素水平低、体重偏轻、年纪增长和缺少体育锻炼等都会造成骨丢失[1-2]。骨量的高低可以通过测量骨密度(bone mineral density，BMD)和骨矿含量(bone mineral content，BMC)来进行评估[3]。研究表明，BMD 越小，越容易受到冲击载荷造成的伤害[4]。通过体育运动能够有效提高 BMD 和 BMC，促进骨骼生长[5]。

不同类型的运动，在特定骨骼区域产生不同的载荷。早期的大鼠实验表明，间歇性的动态运动会产生不同于常规运动的力学载荷，有利于刺激骨骼产生成骨响应[6-9]。篮球、排球和体操等属于高冲击载荷运动，它们能提高全身、腰椎、股骨颈、腿部和双臂 BMD[10]。研究发现，通过 6 个月的高冲击运动，股骨颈 BMD 增加了 2%[11-12]。相反，在进行游泳与自行车等低冲击运动后，下肢 BMD 和 BMC 几乎没有变化[6-7]。高冲击运动更加有利于刺激承重骨骼进行骨重建，提高 BMD 和 BMC，维持骨量[13-15]。

有关多种高冲击运动对 BMD 和 BMC 影响的研究多有报道，然而对比跳伞与篮球运动对 BMD 和 BMC 影响的研究鲜有报道。虽然两者均为高冲击运动，但是以不同的姿势着陆。篮球运动包含跑、走、停和慢慢移动，跳跃着陆时身体稍稍前倾，前脚掌首先着地，然后整个脚掌与地面接触[16]。伞兵要求以半蹲的姿势着陆，并且遵循“三紧一平”的规则，即弯曲双腿，夹紧前脚掌内侧、内踝、双膝，保证着陆时脚掌与地面平行[17]。本文对比了伞兵和篮球运动员 BMD 和 BMC，分析不同姿势着陆的高冲击运动对骨量的影响，为预防骨流失和骨质疏松性骨折提供训练依据。

1 材料与方法

1.1 受试者与分组

招募 39 名男性受试者，伞兵、篮球运动员和作为对照组的普通大学生各 13 名，年龄均为 20 ~ 25 岁。将其分成两组，第 1 组为 20 ~ 22 岁(含伞兵、篮球运动员和对照组各 7 名)，第 2 组为 23 ~ 25 岁(含伞兵、篮球运动员和对照组各 6 名)。受试者分别来自跳伞训练队、篮球运动队和普通大学，无肌骨疾病和骨代谢疾病，并且近 1 年未服用影响骨代谢的药物。问卷调查结果显示，篮球运动员和伞兵每周训练时间约 50 h，而对照组每周运动不超过 1 h。所有受试者的身高、体重以及体质量指数(body mass index，BMI)如表 1 所示。

表 1 受试者体征

Tab. 1 Characteristics of the subjects

分组	第 1 组			第 2 组		
	身高/cm	体重/kg	BMI/($\text{kg}\cdot\text{m}^{-2}$)	身高/cm	体重/kg	BMI/($\text{kg}\cdot\text{m}^{-2}$)
伞兵	179.83 ± 4.02	70.03 ± 6.32	21.83 ± 1.99	174.1 ± 3.70	68.72 ± 4.80	22.62 ± 2.32
篮球运动员	184.29 ± 4.11^{a,c}	75.71 ± 8.01	22.29 ± 1.62	181.17 ± 8.13^{a,c}	76.33 ± 8.45	23.18 ± 1.280
对照组	173.00 ± 6.73	70.66 ± 11.10	23.34 ± 2.68	173.83 ± 2.14	64.33 ± 3.08	21.32 ± 1.23

注：^{a}表示与伞兵具有显著性差异；^{b}表示与篮球运动员具有显著性差异；^{c}表示与对照组具有显著性差异

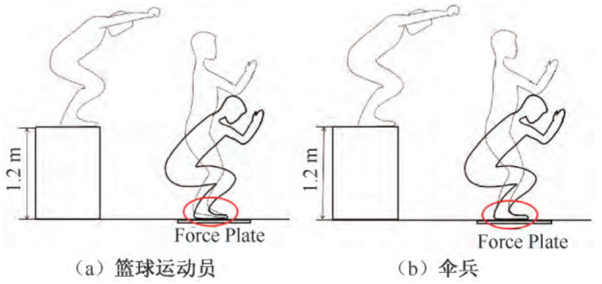
1.2 扫描部位与方法

扫描跟骨、第 1 ~ 5 跖骨、髋关节和腰椎(L1 ~ 4)，处理后分别得到扫描部位的 BMD 和 BMC。扫描时分别将足水平放置、内翻 90°和外翻 45°扫描 3 次，以便清楚区分辨认跟骨和跖骨。在扫描前将测量方法和潜在风险告知受试者，并签署知情同意书。

所有扫描都处于相同环境下，于 2016 年 3 月完成。

1.3　跳台测试

跳台测试要求篮球运动员和伞兵分别从 1.2 m 高平台着陆，通过摄像机分别记录他们的着陆过程（见图 1）。并且使用三维力台（1 kHz，SMA-6，AMTI 公司，美国）采集垂直地面反作用力（vertical ground reaction force，vGRF），采用鞋垫式足底压力鞋垫（100 Hz，Pedar-X，Novel 公司，德国）采集着陆时足部各区峰值压力。



（a）篮球运动员　　（b）伞兵

图 1　不同受试者着陆示意图

Fig. 1　Landing postures of different subjects　(a) Hoopsters, (b) Paratroopers

1.4　数据处理

BMD 和 BMC 数据统计学分析通过 SPSS 13.0 完成，采用独立 t 检验，$P < 0.05$ 表示差异具有统计学意义，$P < 0.01$ 表示差异具有高度统计学意义。足部分区[18] 如图 2 所示，其中 M01 ~ 07 为前足区域，M08 为中足区域，M09 ~ 10 为后足区域。将 vGRF 和各区峰值压力与受试者自身体重（body weight，BW）相比进行标准化。

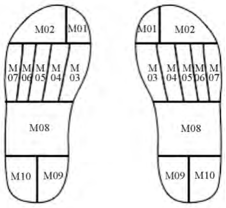


图 2　足底分区

Fig. 2　Partitions of the feet

2　实验结果

2.1　BMC 结果

篮球运动员跟骨、第 1、2 跖骨 BMC 显著大于伞兵（$P < 0.05$）和对照组（$P < 0.01$）。篮球运动员在腰椎和髋关节处 BMC 也显著大于伞兵和对照组（$P < 0.05$），除了第 2 组的 L3 腰椎。所有受试者股骨颈 BMC 无显著性差异。伞兵和对照组扫描部位 BMC 无显著性差异（见表 2）。

表 2　受试者不同部位 BMC 比较

Tab. 2　BMC comparison for different anatomical locations in subjects

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部位	第 1 组（$n=7$）			第 2 组（$n=6$）		
	伞兵	篮球运动员	对照组	伞兵	篮球运动员	对照组
跟骨	27.84 ± 3.89	32.52 ± 5.12^{a,c}	24.58 ± 2.64	23.85 ± 2.98	32.95 ± 9.03^{a,c}	22.82 ± 3.15
第 1 跖骨	6.19 ± 0.85	8.01 ± 1.84^{a,c}	5.68 ± 0.78	6.46 ± 0.81	7.59 ± 1.88^{a,c}	5.64 ± 0.93
第 2 跖骨	3.54 ± 0.36	4.60 ± 0.84^{a,c}	3.15 ± 0.58	3.55 ± 0.43	4.22 ± 0.73^{a,c}	3.34 ± 0.36
第 3 跖骨	3.09 ± 0.38	3.61 ± 1.15^{c}	2.41 ± 0.38	2.67 ± 0.50	2.61 ± 0.88	2.17 ± 0.96
第 4 跖骨	2.90 ± 0.60	2.96 ± 0.79	2.26 ± 0.48	2.65 ± 0.39^{c}	2.50 ± 0.64	2.01 ± 0.29
第 5 跖骨	3.82 ± 0.86	3.59 ± 0.81	3.06 ± 0.73	3.43 ± 0.55	3.51 ± 0.89	2.57 ± 0.47
L1	13.34 ± 1.68	17.29 ± 1.31^{a,c}	13.13 ± 1.87	14.19 ± 1.06	17.20 ± 2.97^{a,c}	12.49 ± 1.47
L2	15.43 ± 1.43	19.70 ± 2.06^{a,c}	15.08 ± 2.52	15.74 ± 1.02	19.84 ± 3.83^{a,c}	14.02 ± 1.01
L3	17.79 ± 1.48	23.03 ± 3.34^{a,c}	17.56 ± 2.26	18.93 ± 2.27	22.50 ± 4.24^{c}	14.88 ± 1.95^{a,b}
L4	19.19 ± 0.93	25.31 ± 2.31^{a,c}	19.42 ± 2.49	19.16 ± 2.57	23.70 ± 4.22^{a,c}	16.09 ± 1.45
总腰椎	65.75 ± 5.16	85.33 ± 8.38^{a,c}	65.19 ± 8.55	68.02 ± 6.46	83.24 ± 14.95^{a,c}	57.47 ± 4.81
左侧股骨颈	5.84 ± 1.33	6.86 ± 0.92	5.41 ± 0.78	4.89 ± 1.73	6.29 ± 1.94	4.51 ± 0.67
左髋	40.51 ± 5.09	58.94 ± 5.05^{a,c}	41.62 ± 3.00	40.86 ± 7.54	53.28 ± 7.56^{a,c}	38.67 ± 5.12
右侧股骨颈	6.46 ± 1.34	6.72 ± 0.72	5.18 ± 0.67^{b}	5.36 ± 1.63	6.73 ± 1.51^{c}	4.14 ± 0.39
右髋	41.96 ± 4.35	57.45 ± 4.61^{a,c}	40.36 ± 5.76	42.96 ± 7.42	53.68 ± 7.50^{a,c}	38.44 ± 4.88

注：^{a} 表示与同组伞兵具有显著性差异；^{b} 表示与同组篮球运动员具有显著性差异；^{c} 表示与同组对照组具有显著性差异

2.2　BMD 结果

跟骨处篮球运动员的 BMD 显著高于对照组（$P < 0.05$）。第 1 组中，第 1 ~ 3 跖骨处篮球运动员 BMD 显著高于对照组（$P < 0.05$）；然而第 2 组中，第

3～5 跖骨处伞兵 BMD 显著高于对照组（$P<0.05$）。篮球运动员髋关节、股骨颈和总腰椎 BMD 显著高于其他受试者（$P<0.01$）。伞兵和对照组跟骨、腰椎和髋关节的 BMC 无显著性差异（见表 3）。对于 BMC 和 BMD，第 1、2 组的测量结果均无显著性差异。

表 3　受试者不同部位 BMD 比较

Tab. 3　BMD comparisons for different anatomical locations in subjects　g/cm^2

部位	第 1 组（$n=7$）			第 2 组（$n=6$）		
	伞兵	篮球运动员	对照组	伞兵	篮球运动员	对照组
跟骨	0.81±0.94	0.75±0.13	0.88±0.92^{c}	0.87±0.14^{c}	0.79±0.48	0.71±0.07
第 1 跖骨	0.49±0.66	0.52±0.09	0.59±0.85^{a,c}	0.56±0.03^{c}	0.50±0.57	0.49±0.05
第 2 跖骨	0.43±0.44	0.43±0.08	0.51±0.64^{c}	0.47±0.04	0.40±0.47	0.41±0.02
第 3 跖骨	0.40±0.75	0.39±0.07	0.43±0.95^{c}	0.33±0.08	0.33±0.33	0.30±0.01^{a}
第 4 跖骨	0.37±0.08	0.38±0.06	0.35±0.05	0.31±0.07	0.30±0.05	0.27±0.03^{a}
第 5 跖骨	0.36±0.09	0.36±0.07	0.35±0.04	0.33±0.07	0.31±0.05	0.28±0.03^{a}
L1	0.96±0.04	1.00±0.08	1.05±0.05	1.11±0.12	0.94±0.10	0.88±0.07
L2	1.00±0.05	1.04±0.11	1.13±0.03	1.20±0.15^{a,c}	1.01±0.10	0.91±0.04
L3	1.04±0.06	1.11±0.13	1.21±0.04^{a,c}	1.23±0.15	1.06±0.10	0.91±0.06
L4	1.03±0.04	1.06±0.15	1.13±0.09	1.19±0.11	1.07±0.06	0.88±0.08
总腰椎	1.01±0.04	1.06±0.12	1.13±0.04^{a,c}	1.19±0.13^{a,c}	1.02±0.08	0.90±0.05
左侧股骨颈	0.96±0.08	0.94±0.15	1.21±0.13^{a,c}	1.18±0.15^{a,c}	0.96±0.10	0.85±0.14
左髋	0.99±0.08	0.99±0.14	1.25±0.09^{a,c}	1.21±0.10^{a,c}	1.05±0.09	0.95±0.10
右侧股骨颈	0.95±0.11	1.02±0.18	1.23±0.08^{a,c}	1.16±0.15^{a,c}	0.95±0.09	0.84±0.10
右髋	0.98±0.08	1.03±0.17	1.24±0.07^{a,c}	1.19±0.09^{a,c}	1.05±0.07	0.94±0.08

注：^{a}表示与伞兵具有显著性差异；^{b}表示与篮球运动员具有显著性差异；^{c}表示与对照组具有显著性差异

2.3　着陆时伞兵和篮球运动员足底压力分布情况

从 1.2 m 高平台着陆时，伞兵双脚的跟骨（M09、M10）压力峰值都显著大于篮球运动员（$P<0.05$）。篮球运动员第 1～5 跖骨（M03～07）的峰值压力显著大于伞兵（$P<0.05$）。篮球运动员和伞兵中足部分（M08）的峰值压力无显著性差异（$P>0.05$，见表 4）。

表 4　从 1.2 m 跳台着陆时双足各区压力峰值对比

Tab. 4　Comparison of plantar pressure peak when landing from 1.2 m-platform　kPa/kg

分区	左足		右足	
	伞兵	篮球运动员	伞兵	篮球运动员
M01	3.41±1.9	3.8±1.16	3.2±0.72	4.14±1.11^{a}
M02	2.38±1.01	2.63±0.957	2.63±0.86	2.94±1.31
M03	3.14±1.58	5.16±1.5^{a}	3.18±1.29	5.23±1.23^{a}
M04	2.89±1.12	4.94±1.86^{a}	3.6±1.89	5.05±2.09^{a}
M05	2.33±0.64	4.25±1.81^{a}	2.86±1.48	4.13±2.21^{a}
M06	1.82±0.49	3.65±1.41^{a}	2.07±1.17	3.44±1.39^{a}
M07	2.23±0.96	3.76±1.32^{a}	2.34±1.25	3.63±1.96^{a}
M08	4.16±2.63	3.52±0.77	5.4±2.43	3.64±0.88^{a}
M09	13.57±2.91	9.49±3.56^{a}	14.82±1.97	9.93±3.24^{a}
M10	12.7±3.42	8.02±3.2^{a}	14.41±2.03	8.52±3.16^{a}

注：^{a} 表示篮球运动员和伞兵在该区域的压力峰值存在显著性差异，$P<0.05$

2.4　着陆时伞兵和篮球运动员 vGRF 情况

着陆瞬间伞兵和篮球运动员 vGRF 对比曲线如图 3 所示。伞兵 vGRF 约为 11 BW，远大于篮球运动员的最大峰值压力（6 BW）。图 3 中伞兵只有 1 个vGRF 峰值，篮球运动员则出现 2 个 vGRF 峰值，第 1 个 vGRF 峰值与第 2 个相差 20～30 ms。配合摄像机分析发现，第 1 个 vGRF 峰值出现在篮球运动员前脚掌着陆时，第 2 个 vGRF 峰值则出现在全脚掌着陆时。伞兵从着陆到稳定的时间明显短于篮球运动员。

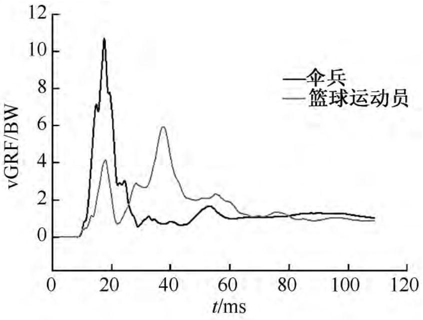

图 3　着陆瞬间伞兵和篮球运动员 vGRF 对比

Fig. 3　vGRF comparison of hoopsters and paratroopers at the moment of landing

3 讨论

不同冲击类型的运动，如篮球、排球、游泳、体操和跑步等对 BMC 和 BMD 有不同的影响。篮球和跳伞作为两种典型的高冲击运动，却较少被对比分析来研究对 BMD 和 BMC 的不同影响。本文选择伞兵和篮球运动员作为研究对象，结合跳台实验采集的 vGRF 和足底分区峰值压力，分析不同着陆姿势和训练方式对不同部位 BMD 和 BMC 的影响。

篮球运动员第 1、2 跖骨处 BMC 显著大于对照组，推测篮球运动能够刺激加载部位的成骨响应、提高承重骨 BMC[19]。但是伞兵与对照组在足部的 BMC 无显著性差异，伞兵在进行着陆时，跖骨峰值压力明显小于篮球运动员，且篮球运动员第 1 个 vGRF 峰值与第 2 个相差 20 ~ 30 ms，前脚掌提前接触地面起到一定的缓冲作用。对于瞬时高冲击运动，篮球运动员的跖骨相比伞兵承担了更多冲击载荷，且第 1、2 跖骨相比其他跖骨所承受的载荷更大，更有效刺激跖骨的骨形成，提高 BMC。

研究表明，篮球运动能够提高下肢 BMD 和 BMC，促进青少年甚至成年人的骨矿积累[15]。本文发现，篮球运动也能显著提高跟骨和髋关节 BMC 和 BMD，而跳伞运动不能明显提高伞兵 BMC 和 BMD。足底分区压力峰值显示，伞兵跟骨相比篮球运动员在着陆瞬间有更大的压力峰值，故骨量的增减与作用与承重骨的载荷大小并不总是正相关，与运动时受到的 vGRF 大小也并非正相关。因此认为，并不是所有的高冲击运动都能显著提高 BMC 和 BMD。

Waener 等[21]研究表明，山地自行车选手所有测量部位的 BMD 显著高于公路自行车选手。山地自行车所面对的地形较为复杂，受到变化频率和强度的载荷作用力，会产生更多的成骨刺激。类似地，在本研究中，篮球运动员腰椎和髋关节处 BMD 显著高于伞兵，因为在篮球运动中包含跑、走、停、慢慢移动和跳跃等各种动作，篮球运动员快速、方向多变的移动，在腰椎和髋关节产生变化的拉力、压缩力、剪切力和弯矩等，会诱导骨形成，提高 BMD[19,21-22]。然而，跳台训练是伞兵的常规训练，在跳台过程中，GRF 是伞兵受到的主要力学刺激。由于变化的载荷较恒定载荷更有利于产生积极的成骨反应[23-24]，故方向多变、速度多变的篮球运动相比受力单一的跳伞运动更容易提高下肢骨量。

本研究的局限性如下：① 受试样本量需要扩大；② 对研究对象的运动史应该进行详细问卷调研，因为青少年时期的运动对于骨量积累和 BMD 高低有重要影响；③ 忽视了对受试者本身运动能力、激素水平等的测量，因为骨量的得失是自身和外界各种因素共同作用的结果。

总体来说，虽然高冲击运动产生的载荷能够刺激骨形成，但 BMC 和 BMD 的增减与载荷大小并不一定成正比。篮球运动能显著提高下肢骨量，在伞兵的日常训练中可考虑采用篮球运动的训练方式提高 BMD 和 BMC，降低骨质疏松性骨折的风险；同时，篮球运动对于普通人的骨量提升也具有重要意义。

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