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The effect of moderate impact exercise on skeletal integrity in master athletes

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Abstract

Summary—We measured bone mineral density (BMD) in senior athletes competing in running and swimming events and compared results to those of sedentary controls. Total body BMD was greatest among runners suggesting that moderate impact activities continue to play a role in maintaining skeletal integrity with age.

Introduction—The role of moderate impact exercise in maintaining skeletal integrity as we age remains unclear.

Methods—To determine the effect of moderate impact exercise on skeletal integrity in the elderly, we recruited master athletes, including 44 runners (moderate impact exercise) and 43 swimmers, competing in the 2005 National Senior Olympic Games and 87 non-athletes, all over the age of 65 years. Height, weight, calcium, vitamin D intake, bone mineral density (BMD) of the total body, spine, hip (total hip, femoral neck, trochanter, intertrochanter), forearm (1/3 distal radius), and heel ultrasound, and Z-scores were characterized by mean $\pm$ SD and compared by analysis of variance. T-scores were used to determine sites of osteopenia and osteoporosis.

Results—Total body BMD of runners was significantly greater than that of controls (1.11 ± 0.13 versus 1.10 ± 0.13 g/cm², $p < 0.05$) and marginally greater than that of swimmers when adjusted for age and weight. Heel ultrasound bone mass of runners was significantly greater than that of swimmers or controls. Runners also had higher BMD in the total hip, intertrochanter and 1/3 distal radius when compared to swimmers.

Conclusion—These findings suggest that moderate impact exercise contributes to skeletal integrity in older age.

Keywords

Bone health; Elderly athletes; Moderate-impact exercise; Osteoporosis

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Introduction

Osteoporosis, a common and serious health concern, is more relevant as our population ages. The Sixth International Symposium on Osteoporosis in 2005 suggested there were 2 million individuals in the US who would experience an osteoporosis-related fracture with an estimated total cost of 16.9 billion [1]. It is anticipated that by 2025 the number of fractures will rise by 48% to 3 million individuals with an associated cost of over 25.3 billion [1]. Beyond the financial implications of osteoporosis, the disease is associated with a significant social burden. Mortality rate from hip fractures is 20% within the first year. Half of patients will be unable to return to their prior state and 10% are placed in long term care facilities [2].

Participation in exercise has long been a cornerstone recommendation for the prevention of osteoporosis. Mechanical loading on bone leads to bone remodeling and formation [1]. Numerous studies have demonstrated a direct relationship between resistance training and bone density [4–7]. Witzke et al offer a classification scheme for impact exercise, defining “high intensity skeletal loading” activities as those which produce ground reaction forces four times body weight, “moderate intensity” as two to four times body weight and “low intensity” as less than two times body weight [8]. Jumping has been shown to produce a force of four to seven times body weight and is therefore, classified as a high impact exercise whereas running produces a force of two to five times body weight and is best classified as moderate impact [8, 9].

While osteoporosis is predominantly a concern of the elderly, the majority of studies on resistance training and bone density have been performed in younger populations [5, 7]. Studies evaluating the effects of impact exercise on maintaining bone density in the elderly are lacking and those that do exist have shown inconclusive results [10–14]. While moderate impact exercise in youth is associated with higher bone density measurements, it is unclear if moderate impact exercise in older age provides similar benefit.

In the summer of 2005, Pittsburgh, PA was host to the National Olympic Senior Games, an event that occurs every four years in different cities across the nation. The event celebrates athleticism among the elderly, organizing competitions in a wide variety of sports for men and women over the age of 50. To compete, participants must show proficiency and dedication to their sport by having won both local and state qualifying events. Thousands of athletes attend representing each of the fifty states and providing a unique sample of the most active and health-conscious men and women in our country. This event offered a unique opportunity to study bone health among athletic older men and women competing in different types of sporting events. We hypothesized that bone mineral density of athletes competing in a moderate impact sporting event, such as running, would be greater than those competing in swimming events or sedentary controls.

Methods

Design and subjects

This was a cross-sectional study that evaluated 87 master athletes including 44 master runners, 43 master swimmers and 87 community dwelling non-athlete controls. Master athletes were recruited from the National Senior Olympic Games hosted by Pittsburgh, PA in the summer of 2005. Inclusion criteria required age ≥ 65 years, a registered competitor in the National Games, and primary training in either running or swimming. Interested athletes were asked to complete a screening survey on site. Individuals were excluded from the study if they were under the age of 65, participating in both running and swimming, or taking medications known to affect bone metabolism including therapies for osteoporosis, hormone replacement therapy, glucocorticoids, or anticonvulsants. Athletes were also excluded if they had a condition known to affect bone metabolism (hyperthyroidism, hyperparathyroidism, end stage renal or liver disease), a history of cancer within the past five years (with the exception of benign skin cancers), bilateral hip replacement, or lumbar spine surgery.

Community dwelling non-athlete controls were recruited from the University of Pittsburgh NIH funded Older American Independence Center Award registry, a database of local elderly over the age of 65 who had demonstrated an interest in participating in research studies. Individuals were contacted by phone and informed of the study. The control participants met the same inclusion criteria specific to medication use and medical conditions, and could not be actively involved in competitive athletics. All participants provided written informed consent to participate in the study. The Institutional Review Board of the University of Pittsburgh approved the study.

Outcomes

All participants were evaluated at the Montefiore Clinical Translational Research Center at the University of Pittsburgh. Height was obtained with a Harpenden stadiometer (Holtain Ltd, Crymych, Dyfed, United Kingdom), weight was measured with a Health-O-meter balance beam scale (Sunbeam, Boca Raton, Florida) and body mass index (BMI) was calculated. Bone mineral density (BMD, g/cm²) of the total body, spine, hip (total hip, femoral neck, trochanter and intertrochanteric sites) and forearm (1/3 distal radius) was assessed by dual energy X-ray absorptiometry (DXA) using a Hologic Discovery A (Bedford, MA). BMD was also evaluated as T-scores (SD from adult peak bone mass) and Z-scores (SD from age-adjusted controls) provided by the manufacturer. T-scores were used to classify athletes according to the World Health Organization system for defining osteoporosis (T-score ≤ -2.5 SD peak bone mass), low bone mass or osteopenia (T-score between -2.5 and -1.0 SD peak bone mass) and normal (T-score ≥ -1.0 SD peak bone mass) [15]. The coefficient of variation for our DXA machine is 1.3% for the spine and 1.4% for the total hip [16]. Percentage of fat and lean body mass were also obtained from the whole body scans to determine body composition. Bone mass of the heel was assessed as stiffness units (SI) from calcaneal ultrasound using a Lunar Achilles InSight Works (GE Madison, Wisconsin). Participants completed food frequency questionnaires to evaluate calcium and vitamin D intake in their diet and vitamin supplements [17].

Statistical analysis

SAS® version 9 (SAS Institute, Inc., Cary, North Carolina) was used for all statistical analyses. A general linear model was fitted using the GLM procedure with each measure of BMD as the response variable; and subject group (runners/swimmers/controls) and gender as main factors of interest. Age and weight were included as covariates to obtain adjusted differences. Appropriately constructed means contrasts were used to make the comparisons of interest: across subject groups, across subject groups within gender, and between genders within subject group. T-scores were used to determine sites of osteopenia and osteoporosis, according to the WHO classification system. Percentage of subjects with osteopenia and osteoporosis at each site was compared across groups within each gender.

Results

Clinical characteristics

Mean age among the runners and swimmers was 73 years and this was similar to the control group with a mean age of 75 years (Table 1). All three groups were predominantly Caucasian and included more men than women. Percentage of women was similar including 34% in the runners, 42% among the swimmers and 31% in the controls. All groups had a similar percentage of participants with a college education or higher and most participants in the three groups were married. Although the height of the participants did not differ significantly between groups, there were significant differences in weight and BMI (both $p < 0.01$, Table 1). There was no significant difference in smoking history or fracture history as an adult. Food frequency questionnaire results revealed significant differences in dietary calcium intake ($p < 0.01$) but not in vitamin D intake (Table 1).

Bone mineral density

When adjusted for age and weight, total body BMD in runners (1.11 ± 0.13 g/cm²) was marginally greater than that of swimmers (1.10 ± 0.11 g/cm², $p < 0.1$) and significantly greater than that of the controls (1.10 ± 0.13 g/cm², $p < 0.05$) (Table 2). There was no difference in total body BMD between the swimmers and the controls. Total hip BMD was also marginally greater in the runners than swimmers ($p < 0.1$). Runners had a significantly greater BMD in the hip intertrochanter when compared to swimmers ($p < 0.05$) but not when compared to controls. BMD of the 1/3 distal radius was slightly higher in runners than in swimmers or controls. The calcaneal stiffness index of runners (104.81 ± 22.95 SI) was significantly greater than that of swimmers (94.71 ± 19.31 SI) or controls (95.39 ± 2.25 SI).

BMD and gender

When the athlete groups were compared to controls of the same gender and results were adjusted for age and weight, there were no significant differences between BMD of female runners, swimmers and controls at any site (data not shown). Among the males, runners had significantly lower spine BMD than controls (1.04 ± 0.15 vs 1.17 ± 0.19 g/cm²). The remainder of the comparisons were not significantly different.

Percentage of participants with osteopenia and osteoporosis

Among the female runners, percentage of osteopenia ranged from 20% of subjects in the trochanter site to 73% of subjects in the femoral neck (Fig. 1). The site with the highest percentage of osteoporosis in female runners was the 1/3 distal radius. Among female swimmers, percentage of osteopenia ranged from 16% of subjects in the spine to 61% of subjects in the femoral neck. The 1/3 distal radius was also the site with the highest percentage of osteoporosis. Percentage of osteopenia in the female control group ranged from 30% in the spine to 55% in the femoral neck and the highest percentage of osteoporosis was found in the spine. There were no statistically significant differences between groups in this analysis.

Among the male runners, percentage of osteopenia ranged from 21% at the trochanter to 52% at the femoral neck, with an equal percentage of osteoporosis in the spine, femoral neck and 1/3 distal radius (Fig. 2). Percentage of osteopenia among male swimmers ranged from 17% in the spine to 58% in the femoral neck with the highest percentage of osteoporosis in the 1/3 distal radius. In the male control group, percentage of osteopenia ranged from 14% in the spine to 48% in the femoral neck, with the highest percentage of osteoporosis again in the 1/3 distal radius. The percentage of male controls with normal BMD at the spine was significantly greater than the male runners and swimmers ($p < 0.05$). There were no other significant differences between groups.

Z-scores of athletes vs. controls unadjusted for weight or BMI

Mean Z-scores of female athletes and controls were greater than zero at all sites except the femoral neck in runners (Fig. 3). Mean Z-score ranges for female runners (0.28 to 1.01 SD), female swimmers (0.66 to -1.03 SD) and female controls (0.99 to 2.11 SD) were similar at all sites except the spine. Spine Z-score of female controls (2.11 ± 1.62 SD) was significantly greater than that of female runners (1.01 ± 1.33 SD) but not greater than that of swimmers (1.63 ± 1.29 SD). Mean control female intertrochanter hip and total hip Z-scores were also slightly greater than those of female runners but not swimmers.

Mean male Z-scores were greater than zero at all sites among the controls (Fig. 4). In the male runners, Z-scores were only greater than zero in the total hip and 1/3 distal radius. In the male swimmers, Z-scores were only greater than zero in the spine. Mean Z-score ranges among runners (0.14 to 0.76 SD), swimmers (0.19 to 1.28 SD) and controls (0.34 to 1.70 SD) were similar at all sites except the spine. Spine Z-scores were significantly greater in the swimmers (1.28 ± 0.35 SD) and controls (1.70 ± 0.23 SD) as compared to the runners (0.34 ± 0.24 SD).

Discussion

When adjusted for age and weight, we found that athletes had greater total body BMD than sedentary controls. The difference was most notable between the runners and controls and less significant between the runners and swimmers. When compared to all swimmers, runners also had significantly greater BMD at the intertrochanter and marginally greater

BMD at the total hip and 1/3 distal radius. Calcaneal stiffness indices among runners was significantly greater than that of swimmers or controls.

Several areas where runners had greater BMD than swimmers (intertrochanter and 1/3 distal radius) were characterized by skeletal sites rich in cortical bone. Skeletal areas with predominantly trabecular bone (ie: trochanter, spine) did not show a higher BMD in runners when compared to swimmers. This may suggest that moderate-impact exercise preferentially affects sites rich with cortical bone. Previous studies have found impact exercise to affect certain skeletal sites and bone types more than others [18–21]. In a younger cohort, Rico et al compared trabecular and cortical bone mass in the dominant and non-dominant extremities.

They found that while there was no difference in trabecular bone mass between extremities, cortical bone mass was significantly greater in the dominant extremity [22]. Blain et al studied BMD in older women and found that quadriceps strength correlated with higher femoral neck bone density but did not affect spine bone density, a site of predominantly trabecular bone [23]. Our study supports the theory that moderate impact exercise favors cortical bone development. However, the greater calcaneal ultrasound density seen among runners argues against this since the heel is a site rich in trabecular bone. Nevertheless, the heel is also the site that receives the greatest amount of impact in running suggesting that trabecular bone does respond to moderate levels of impact.

There were no significant differences between BMD among female athletes and female controls at any site. There were also no significant differences in the percentage of osteopenia and osteoporosis at each site among females. Interestingly, all groups had a high percentage of osteopenia at the femoral neck and a high percentage of osteoporosis at the 1/3 distal radius. Among the males, there were also no significant differences between BMD of controls and athletes. As expected, there were less sites of osteoporosis in the males than the females. Of note, the male controls had a significantly greater percentage of normal BMD at the spine than male runners or swimmers, an observation that will be considered further.

The finding that the control females and males had mean Z-scores that were significantly greater than zero at all sites suggests their bone mineral density was above the national average of participants their age and gender. However, weight and BMI also contribute to bone mass [24–26], and the group of controls had the greatest weight of all three groups. The mean BMI of our control group was 28 kg/m² which is comparable with the national average of 28.1 kg/m² for non-hispanic whites in this age group [27].

The female athletes had mean Z-score values that were greater than zero at many more skeletal sites than the male athletes. Among female athletes, Z-scores were greater than zero at all sites except the femoral neck in female runners. In comparison, male runners' Z-scores were only significantly different from zero at 2 sites (total hip and 1/3 distal radius) and male swimmers only had spine BMD that was significantly above zero. This finding may suggest that athletic training in older age is particularly important for females. By participating in competitive sports these female athletes were able to maintain bone densities at most sites that were well above the national average of females their age. While male

athlete Z-scores were not unfavorable, they did not prove to be significantly different from those of the general population. Finally, it is important to note that although there were few differences in Z-score values between groups, spine Z-scores in both the female and male control groups were significantly greater than those of the respective runners. This difference was most notable between the male runners and controls but also held true between the male swimmers and runners. Z-scores are not adjusted for weight and our controls had significantly greater weight than the athletes. This may contribute to the higher Z-scores of the controls and supports the need to include controls for comparison so weight can be factored in. Furthermore, because osteophyte calcifications may falsely elevate PA spine BMD measurements and body weight also contributes to osteoarthritis [28], it is possible that osteoarthritis contributed to this finding. A lateral spine BMD may have been beneficial to assess for posterior calcifications but this was not done in this study.

The study had several limitations that must be addressed. While inclusion criteria specified that a participant could only be competing in either running or swimming, athletes in all sports participate in resistance exercises as well to improve their performance. We were not able to assess this training. Furthermore, some athletes may have competed in running events when they were younger but due to the progression of arthritis switched to competitive swimming. As arthritis of the spine may falsely elevate the PA spine BMD measurements, this explanation may explain why male swimmers had spine Z-scores that were greater than those of male runners. Information on life long physical activity was limited among all participants and this was an important study limitation. Despite efforts to acquire a detailed record of exercise type and intensity, the cross-sectional nature of this study made it difficult to obtain consistent information on life long exercise in an elderly population. The authors realize that obtaining an exercise history in the control group is of particular importance in order to distinguish them from the athlete population. Control participants may have participated in routine physical activity as well and may have been in better physical condition than some of the athletes. However, there are two points to consider which make this possibility less likely. First of all, only individuals who were not currently active at a competitive level were included in the control group. Second of all, in order to be invited to the National Senior Games, athletes had to place 1st, 2nd, or 3rd in their state. While the authors would have preferred to have a more complete exercise history on the participants, the authors feel that through their invitation to the National Senior Games, the athletes achieved an athletic status that clearly distinguished themselves from other physically active members of the elderly community. The cross-sectional nature of the study also introduces the problem of ascertainment bias. The subject's baseline skeletal status may have influenced their decision to pursue running versus swimming, or vice versa. Thus, baseline skeletal status may have more of an effect on activity style than we fully appreciate and this consideration must not be ignored.

The study was also limited by the number of participants. Whereas there were over 15,000 athletes competing in the National Olympic Senior Games, many of the participants were between the ages of 55–65 and several of our possible candidates had to be excluded due to their current medications or because they were competing in multiple events. Finally, our study group was biased in terms of race and socio-economic class. All three groups were predominantly Caucasian and most subjects had at least a college education. These factors

are likely to influence their ability to exercise at the competitive level, receive routine health care and maintain appropriate levels of calcium and vitamin D in their diets.

The study design also had several important strengths. This study is among the first to evaluate the effects of both running and swimming on bone mineral density in a very active group of elderly men and women. We were able to include a unique sample of the elderly population during the 2005 National Senior Olympic Games in Pittsburgh. Unlike many studies which have focused on bone density at one particular skeletal site, we measured BMD at multiple sites. We also included a group of local sedentary controls from the Pittsburgh community to compare to the runners and swimmers in addition to the control directly supplied by the manufacturer's density database. This allowed us to adjust for weight which may contribute to bone mass and is not factored into standardized Z and T-scores.

In summary, in our comparison of BMD among competitive elderly runners and swimmers, we found that total body BMD in elderly runners was significantly greater than that of sedentary controls and marginally greater than that of swimmers. Moderate impact exercise, therefore, may contribute to higher bone mineral density in the older population. In the future, a larger cohort and longitudinal follow up would be of value to examine the rate of change of BMD at these skeletal sites among athletes and controls. This study supports the recommendation that elderly men and women should participate in moderate impact activities to maintain their skeletal health.

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Figure 1.
Percentage of female athletes and controls classified as normal, osteopenic (low bone mass) or osteoporotic at each skeletal site: Run = runners, Swim = swimmers

Figure 2.

Percentage of male athletes and controls classified as normal, osteopenic (low bone mass) or osteoporotic at each skeletal site: Run = runners, Swim = swimmers

Figure 3.

Z-scores (SD) $\pm$ standard error of the mean of female athletes and controls, * $p < 0.05$ from zero

Figure 4.
Z-scores (SD) $\pm$ standard error of the mean of male athletes and controls, * $p < 0.05$ from zero

Table 1

Clinical characteristics of the subjects

	Runners	Swimmers	Controls
N	44	43	87
#Females (%)	15 (34)	18 (42)	31(36)
#Caucasian (%)	40 (91)	39 (91)	75(86)
Age (years)	73.3 ± 7.1	72.6 ± 6.8	75.3 ± 5.4
College or higher education (%)	66	74	42
# Married (%)	34 (77)	28 (65)	63 (72)
Height (cm)	167.7 ± 7.2	168.3 ± 10.2	168.0 ± 8.9
Weight (kg) *	66.5 ± 10.9	77.3 ± 13.4	79.7 ± 11.9
BMI (kg/m ²) *	23.5 ± 2.6	27.2 ± 3.8	28.3 ± 3.9
Calcium (mg/day) *	1853 ± 887	1577 ± 709	1213 ± 623
Vitamin D (IU/day)	762 ± 395	726 ± 367	702 ± 371
>100 cigarettes smoked in lifetime	11 (25)	20 (47)	45 (52)
History of fracture	9 (20)	11 (26)	12 (14)

*
p < 0.01 across groups

Results as mean ± SD

Table 2

Bone mineral density and heel ultrasound of participants

Site	Athletes (mean $\pm$ SD)		Controls (mean $\pm$ SD)	Adjusted pairwise differences ⁺		
	Runners	Swimmers		Runners vs Swimmers	Runners vs Controls	Swimmers vs Controls
BMD (g/cm ²) [‡]						
N	44	43	87			
Total body	1.11 $\pm$ 0.13	1.10 $\pm$ 0.13	1.10 $\pm$ 0.13	0.05 [*]	0.05 ^{**}	0.00
Spine	1.00 $\pm$ 0.17	1.11 $\pm$ 0.20	1.11 $\pm$ 0.20	-0.012	-0.03	-0.02
Hip						
-Total hip	0.94 $\pm$ 0.16	0.95 $\pm$ 0.15	0.95 $\pm$ 0.15	0.06 [*]	0.04	0.03
-Femoral neck	0.74 $\pm$ 0.13	0.77 $\pm$ 0.13	0.77 $\pm$ 0.13	0.03	0.02	-0.01
-Trochanter	0.73 $\pm$ 0.15	0.74 $\pm$ 0.14	0.74 $\pm$ 0.14	0.04	0.04	-0.00
-Intertrochanter	1.11 $\pm$ 0.19	1.12 $\pm$ 0.17	1.12 $\pm$ 0.17	0.08 ^{**}	0.03	-0.03
1/3 Distal radius	0.72 $\pm$ 0.10	0.72 $\pm$ 0.10	0.72 $\pm$ 0.10	0.04 [*]	0.04 ^{**}	0.00
Heel ultrasound	104.81 $\pm$ 22.95	94.71 $\pm$ 19.31	95.39 $\pm$ 2.25	0.83 ^{***}	0.69 ^{**}	-0.15

⁺ Results adjusted for age and weight

[‡] BMD as g/cm² except heel ultrasound reported as Stiffness Index (SI) units

^{*} 0.05 < p < 0.10 pairwise differences

^{**} 0.01 < p < 0.05 pairwise differences

^{***} p < 0.01 pairwise differences