ORIGINAL ARTICLE

Bone mineral density in female runners, swimmers, and water polo athletes: Comparisons across sports with different impacts

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ABSTRACT

Bone mineral density (BMD) is a measure of bone health which reflects risk for osteoporosis. Different types of exercise induce divergent impact on the skeleton influencing accrual of BMD. Previous research reported that female collegiate athletes in aquatic sports had lower BMD than other athletes and controls. PURPOSE: The goal of this study was to conduct a modern comparison of BMD of athletes in weight-bearing and non-weight-bearing sports with normally active controls. METHODS: Height, weight, and calcium intake was assessed in collegiate females (20.0 ± 1.3 years); 39 runners, 9 swimmers, 16 water polo players, and 24 controls. BMD and bone free lean mass were measured via dual-energy x-ray absorptiometry (DXA) at baseline and 5 months later. RESULTS: When controlling for calcium intake and lean mass, there were no statistical differences between groups in BMD at the anterior-posterior (AP) spine, lateral spine, trochanter, total hip, and whole body. At the femoral neck (FN), water polo players had greater BMD than swimmers (0.922 ± 0.030 vs. 0.790 ± 0.033 g/cm^2, p = .005). Longitudinally, increases in BMD between visits occurred for swimmers at the AP spine (p = .028), lateral spine (p = .049), FN (p = .049), and trochanter (p = .018) and for controls at whole body (p = .008). CONCLUSION: Bone health in female aquatic athletes was similar to controls and runners, except at the FN where BMD of swimmers was less than water polo players. Some females may continue to accrue BMD in college years. Modern training methods among female college athletes may lead to similar bone health even in sports with different skeletal impact.
Keywords: Sport medicine, Osteoporosis, Calcium, College, Weight-bearing, Aquatic sports.

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INTRODUCTION

Osteoporosis is a chronic disease featuring low bone mineral density (BMD) and skeletal fragility. When BMD is lower than normal, individuals are at a higher risk for osteoporosis and suffer increased risk for fracture due to reduced bone strength. Osteoporosis may occur if peak bone mass is not achieved during youth which emphasizes the value of optimizing bone health as an emerging adult (Gunter et al., 2011). Research shows that lifestyle behaviours account for 20-40% of adult bone mass, with special emphasis on calcium intake and physical activity during youth for optimal development of peak bone mass (Weaver et al., 2016). Approximately 10 million Americans have been diagnosed with osteoporosis and another 43 million suffer from low bone mass which predisposes someone to osteoporosis (Wright et al., 2014). According to the U.S. Centers for Disease Control, women are nearly 5 times more likely than men to have osteoporosis at the femoral neck or lumbar spine after the age of 50 (Sarafrazi et al., 2021). One way for women to lower risk for poor skeletal health is to participate in sports, especially during adolescence and young adult years.

Weight-bearing activity and participation in sports with impact loading achieve an osteogenic effect that enhances bone properties, including bone size, architecture, strength (Kohrt et al., 2004). In vivo analysis of BMD may be one of the best measures of bone strength accounting for up to 60% of the strength of the skeleton (Weinstein, 2000). Children should engage in impact activities for 10-20 minutes, three times a week in order to stimulate proper bone formation prior to peak bone mass accrual (Kohrt et al., 2004). As adults, maintaining healthy BMD levels can be achieved by engaging in weight-bearing physical activity with high bone-loading forces, 3-5 times a week and resistance training 2-3 times per week, for 30-60 minutes (Kohrt et al., 2004). Following these exercise prescriptions may help decrease risk for osteoporosis and fracture later in life while stimulating the necessary osteogenic response to achieve optimal peak bone mass and maintain healthy BMD levels throughout life.

Participation in collegiate athletics has expanded greatly in the last 50 years for female athletes. National championships for female collegiate athletes in the United States began in 1967, with gymnastics added in 1969, swimming in 1970, cross country running in 1982, and women's water polo in 2001 (Bell, 2007; Whitaker, 2023). The number of women competing in the National Collegiate Athletic Association (NCAA) increases annually, with a record-breaking 235,735 female athletes in 2024 (McGuire, 2025). To improve performance and help avoid injury, strength and resistance training has increased greatly among female athletes. Resistance exercise has become an essential component of high-level training protocols because of the substantial performance benefits. In addition, resistance training is widely known to benefit skeletal health and increase BMD (Haff and Triplett, 2015; Kohrt et al., 2004).

Studies conducted in the late 1990's by Taaffe et al. reported that females in non-weight-bearing sports, such as swimming, exhibit lower BMD than those in weight-bearing sports, like gymnastics and running (Taaffe et al., 1997; Taaffe et al., 1995). For female athletes, the beneficial weight-bearing stimulus of gymnastics during adolescence facilitated peak bone mass development that outweighed the stimulus of the forceful muscle contractions of swimming (Taaffe et al., 1995). Of note, was Taaffe's report that a control group of non-athletes in those studies had greater BMD than swimmers at the femoral neck and trochanter, even though the swimmers engaged in about 22 hours of training each week. Taaffe et al. attributed this finding to the amount of time swimmers spent in a non-weight-bearing environment which would negate the positive effect of swimming exercise (Taaffe et al., 1995). Longitudinally Taaffe et al. found that gymnasts experience the greatest long-term benefits to BMD which should be attributed to the high-impact bone loading characteristics of the sport. Over 12 months, the changes in BMD experienced by gymnasts were greater than both swimmers and controls (Taaffe et al., 1997), however this research did not make direct comparison between swimmers and runners.

In an investigation measuring bone strength via peripheral quantitative computed tomography, water polo athletes had similar skeletal measures to controls in the lower leg but were greater than controls at the distal radius (Greene et al., 2012). Other researchers found evidence that BMD redistribution occurs among male water polo athletes from the lower extremities to the upper extremities (Kavouras et al., 2006). When compared to handball athletes and controls, water polo athletes had greater BMD in the upper extremities but less BMD in the lower extremities than controls. Direct comparisons of bone health between female swimmers, water polo players, runners, and controls are lacking but necessary to better understand the influence of the varying load patterns of these sports.

The purpose of this study was to revisit previous findings by comparing the BMD of athletes in weight-bearing and non-weight-bearing sports with normally active controls. Specifically, we sought to assess bone health in current female collegiate runners, swimmers, and water polo players. We also aimed to assess whether female collegiate athletes experienced changes in BMD over one competitive season (about 5 months). We hypothesized that BMD in female athletes of weight-bearing and non-weight-bearing sports would be more similar today than in results from the 1990's (Taaffe et al., 1997; Taaffe et al., 1995) due to a greater emphasis on resistance training and better understanding of peak bone mass development during adolescence.

MATERIALS AND METHODS

Participants

The female athletes in the study were recruited from NCAA Division 1 cross country, swimming, and water polo teams. Normally active females of a similar age were recruited from the same institution to serve as controls. Participants were excluded if they were pregnant or under the age of 18. The runners trained 9-10 bouts in a week accumulating about 100 km. Swimmers exercised 8-11 times per week for 1-3 hours each session. Water polo athletes practiced 8-9 sessions per week averaging 2-4 hours per day. To evaluate changes in bone health over time, participants were asked to return to repeat testing at the conclusion of their competitive season, approximately 5 months later.

Prior to joining the study, all volunteers were educated about study procedures and gave informed consent to participate. The study methods and procedures were approved by a university Institutional Review Board for the Protection of Human Subjects. This research was carried out in accordance with the ethical standards of the National Health Council and to the Declaration of Helsinki for research involving human subjects. Each researcher was educated on ethical standards of the Helsinki Declaration prior to contributing to the study.

Anthropometrics and questionnaires

Height in centimetres and weight in kilograms were measured two times each on an electric scale with attached stadiometer (Seca Accu-Hite, Columbia, MD, USA). Participants were asked to wear lightweight clothing and remove shoes or any bulky clothing. The average of the two measures is reported.

Demographics and menstrual information were collected via a health history questionnaire. Calcium intake was assessed via rapid assessment method (Henry and Almstedt, 2009). Participants were asked to identify the calcium-containing foods and supplements on the food frequency questionnaire consumed in the last week and how many servings of each. The questionnaire was scored by summing all dietary calcium intake for the week and dividing by seven.

Physical activity was quantified using a Physical Activity Questionnaire (Pereira et al., 1997). Participants recorded which activities they participated in regularly for the last three months and how many minutes a week they spent doing them. The Physical Activity Questionnaire (PAQ) was scored by summing the number of MET-hours per week. The PAQ also provided information about cross-training activities, including resistance training.

Bone mineral density and lean mass

BMD analysis of the anterior-posterior (AP) spine, lateral spine, trochanter, femoral neck (FN), and whole body was made using dual-energy x-ray absorptiometry (DXA; Hologic Delphi A, Waltham, MA, USA). Our laboratory produces a 1.0% test-retest reliability using DXA for scans of the spine, hip, and whole body. DXA scans were taken by the same technician at each visit. Lack of pregnancy was confirmed via urine dipstick test to ensure safety prior to beginning scans. The whole body scan was used to calculate bone free lean mass (BFLM) in kilograms which was used as a covariate for statistical analysis.

Statistical analysis

Data was analysed using IBM SPSS version 27 (IBM Corporation, Armonk, New York) statistical package for Windows. An alpha level of .05 or less was used to establish statistical significance. Differences in age, height, weight, body mass index (BMI), BFLM, calcium intake, and physical activity were compared using an analysis of variance, with a Bonferroni post-hoc test. To evaluate differences in BMD at baseline, a two-tailed analysis of covariance (ANCOVA) was performed with a Bonferroni correction. Because lean mass accounts for more than 20% of variance in BMD (Ho-Pham et al., 2014), BFLM was used as a covariate. Statistical analyses were also controlled for calcium intake. Changes in BMD over time were evaluated with a repeated-measures ANCOVA, also with Bonferroni correction. Effect size was evaluated using Cohen's d when significant differences were discovered. Effect sizes were interpreted as large (≥0.8), medium (0.5-0.79), small (0.2-0.49), or non-existent (0-0.19) (Cohen, 1988).

RESULTS

In total, 88 females volunteered for the study, including 39 runners, 9 swimmers, 16 water polo players, and 24 controls. Participant demographics are displayed in Table 1. Age between groups did not differ. Height, weight, BMI, and BFLM were significantly different between groups. Specifically, BFLM was greater in swimmers and water polo athletes than in runners or controls. Calcium intake of runners was significantly greater than all other groups. Physical activity per week also differed among groups. Water polo athletes recorded the most MET-hours per week, and as expected, all athletes recorded more MET-hours than the controls. Beyond running, the cross country athletes did two, 1-hour resistance training sessions and two, 1-hour aqua jogging sessions weekly. Water polo athletes were resistance training 3 times per week in the off-season months (September-December) and 2 times per week while in season (January-May). Swimmers and runners were resistance training 2 times per week during the academic year. Among all volunteers, 43% (n = 38) were using hormonal contraceptives. Three runners, one swimmer, and one water polo player were experiencing amenorrhea when they enrolled in the study.

Table 2 displays the average bone health variables at baseline. When controlling for calcium intake and BFLM, all groups were found to have similar BMD at the AP spine, lateral spine, trochanter, total hip, and whole body. However, swimmers had 14.3% lower BMD than water polo players at the FN (p = .004, d = 1.96).

At visit two 18 runners, 11 water polo players, 8 swimmers, and 24 controls returned for follow-up DXA scans. Reasons for not returning for the longitudinal analysis included a busy schedule, lack of interest, leaving the team, injuries which prevented training, and illness with COVID-19. Figure 1 displays changes in BMD among the four groups at each bone site. The longitudinal analysis showed that returning swimmers increased in BMD during the five-month period between tests. Significant increases were measured for swimmers at the AP spine (p = .028, d = 1.05), lateral spine (p = .049, d = 1.67), FN (p = .049, d = 0.50), and trochanter (p = .018, d = 0.58). BMD changed by 1.8% at the AP spine, 3.7% at the lateral spine, 4.2% at the FN, and 2.1% at the trochanter. Controls, runners, and water polo athletes experienced small, non-significant changes in BMD during the 5-month period. Swimmers were the only athletes to experience substantial gains in bone mass, while controls had a significant increase in whole body BMD (p = .008, d = 0.43).

Table 1. Demographic data for participants at baseline. Data is reported as mean ± standard deviation for quantitative variables or as percent and number for nominal variables.

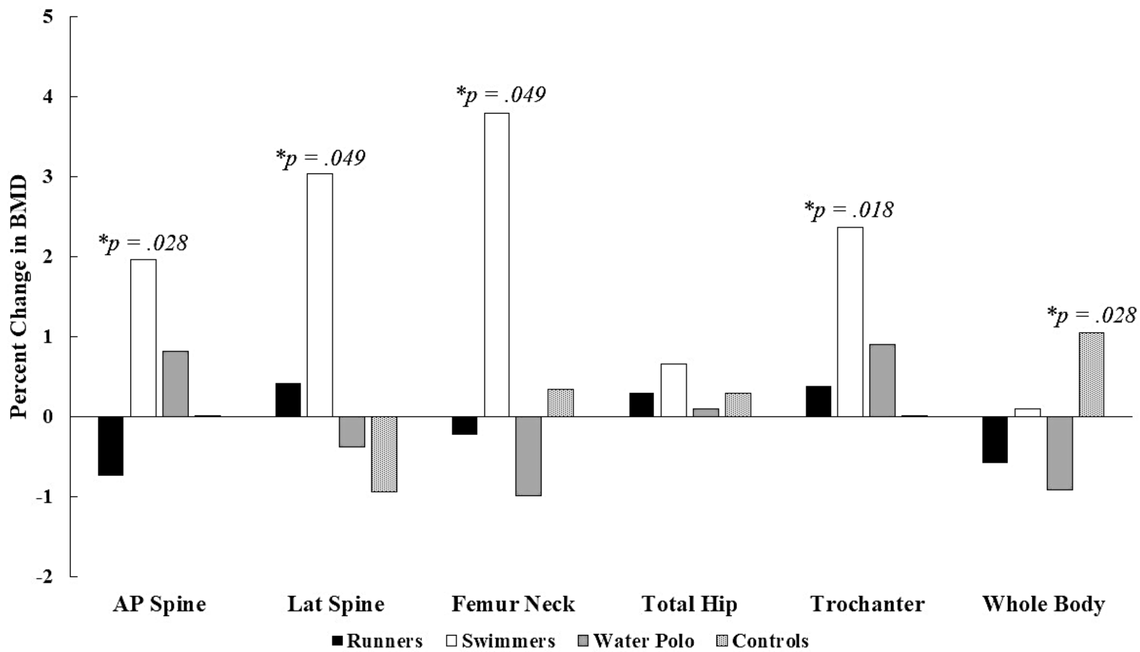
Variables	**Runners n = 39**	**Swimmers n = 9**	**Water polo n = 16**	**Controls n = 24**	***p*-value**
Age (years)	19.95 ± 1.50	19.47 ± 1.07	20.52 ± 1.58	19.75 ± 0.58	NS
Height (cm)	164.13 ± 5.74	166.78 ± 1.07	169.20 ± 8.24	162.24 ± 6.02	WP>C p =.004
Weight (kg)	54.28 ± 5.20	66.38 ± 4.77	75.84 ± 12.76	54.79 ± 5.05	WP>S p =.012 S>C p < .001 R<S, WP p < .001
BMI (kg/m^2)	20.13 ± 1.42	23.89 ± 2.04	26.48 ± 4.20	20.88 ± 1.20	WP>S p = .036 S>C p = .004 R<S, WP p < .001
Bone free lean mass (kg)	39.66 ± 3.63	45.00 ± 3.56	49.26 ± 6.31	37.40 ± 3.18	S>R p = .004 S>C p < .001 WP>C, R p < .001
Race and Ethnicity	61.5% W (n = 24) 33.3% H (n = 13) 5.1% A (n = 2)	77.8% W (n = 7) 22.2% A (n = 2)	81.3% W (n = 13) 18.8% H (n = 3)	37.5% W (n = 9) 12.5% H (n = 3) 45.8% A (n = 11) 4.2% Other (n = 1)	
Calcium intake (mg/day)	1365.02 ± 643.89	409.33 ± 126.22	632.31 ± 325.15	884.31 ± 357.74	R>C p = .002 R>S, WP p < .001
Physical activity (MET-hrs/wk.)	110.13 ± 7.34	108.82 ± 11.73	188.26 ± 9.09	23.40 ± 7.19	C<R, S, WP p < .001 WP>R, S p < .001
Menstrual status	E: 35.9% (n = 4) O: 10.3% (n = 4) A: 7.7% (n = 3) HC: 46.2% (n = 18)	E: 44.4% (n = 4) O: 0 A: 11.1% (n = 1) HC: 44.4% (n = 4)	E: 62.5% (n = 10) O: 0 A: 6.3% (n = 1) HC: 31.3% (n = 5)	E: 50% (n = 12) O: 4.2% (n = 1) A: 0 HC: 45.8% (n = 11)	

Note. NS = nonsignificant, WP = water polo, S = swimmers, R = runners, C = controls, BMI = body mass index, W = white, H = Hispanic, A = Asian, MET-hrs/wk. = metabolic equivalent hours per week, E = eumenorrheic, O = oligomenorrheic, A = amenorrhoeic, HC = using hormonal contraceptives.

Table 2. Mean bone mineral density (BMD) and standard error at each site.

BMD (g/cm^2)	**Runners n = 39**	**Swimmers n = 9**	**Water Polo n = 16**	**Controls n = 24**
AP Spine	0.971 ± 0.019	0.937 ± 0.038	1.039 ± 0.035	1.010 ± 0.024
Lateral Spine	0.762 ± 0.019	0.699 ± 0.039	0.755 ± 0.034	0.763 ± 0.023
Femoral Neck	0.886 ± 0.017	0.790 ± 0.033*	0.922 ± 0.030	0.890 ± 0.020
Trochanter	0.789 ± 0.015	0.702 ± 0.031	0.758 ± 0.028	0.774 ± 0.019
Total Hip	1.018 ± 0.017	0.912 ± 0.035	0.979 ± 0.032	1.004 ± 0.021
Whole Body	1.092 ± 0.013	1.020 ± 0.026	1.055 ± 0.024	1.050 ± 0.016

*Note. *p = .004, S significantly lower BMD at the femoral neck than water polo athletes when controlling for bone-free lean mass and calcium. BMD = bone mineral density, AP = anterior-posterior.*



*Note. *Significant change between initial and follow up visit when controlling for BFLM and calcium. BMD = bone mineral density, AP = anterior-posterior, Lat = lateral*

Figure 1. Percent change in BMD between baseline and 5-months later at six bone sites. Controls showed no change at the AP spine or trochanter.

DISCUSSION

We report that when controlling for calcium intake and BFLM, female collegiate athletes in weight-bearing (running) and non-weight-bearing sports (swimming and water polo) have similar BMD to each other and controls, except at the FN. Swimmers in this study showed significantly lower BMD than water polo players at this important bone site. Further, despite having lower BMD at the FN in cross-sectional comparisons, swimmers were the only athletes in this study that showed significant increases in BMD over the 5-month competitive season with meaningful changes in both views of the spine and two of the hip sites (FN and trochanter). Even though, changes in BMD of 1.8-4.2% may appear small compared to some physiological measures, previous research shows this is clinically relevant and may relate to a reduction in fracture risk of 13-42%, later in life (Wasnich and Miller, 2000). Non-athletes also increased significantly in BMD of the whole body. Perhaps, the principle of initial values partially explains why the swimmers increased in BMD and runners or water polo athletes did not (Winters-Stone and Snow, 2003). The initial values principle of exercise science suggests that people with the lowest baseline values have the largest propensity towards improvements due to training.

Lower BMD observed at the FN in swimmers is particularly important due to the clinical significance of bone mass at this site. The FN is the primary bone site used for diagnosis of osteoporosis and assessment of fracture risk (Leslie et al., 2011). Large epidemiological studies establish the FN as the bone site most predictive of future fractures (Johnell et al., 2005). Thus, the lower BMD at the FN in the female collegiate swimmers of this study is especially concerning. On the other hand, the roughly 2.0-3.8% increase in BMD at four bone sites among swimmers suggests that these women are still working towards peak bone mass.

Despite the substantial hours of non-weight-bearing activity in the pool each week, the female swimmers in this study increased bone mass over 5 months of training. These results differ from research of more than 20 years ago showing that collegiate swimmers had lower BMD than runners, gymnasts, and even non-athletes (Taaffe et al., 1995). Further, the swimmers in the study by Taaffe et al. exhibited <1% change in BMD after 12 months of training (Taaffe et al., 1997).

Perhaps the modern incorporation of prescribed resistance training programs aimed to improve performance can help explain the differences in results reported in this investigation compared to prior work. While vague in nature, for swimmers, Taaffe et al. reported "*approximately 2 h/week each of resistance training and aerobic activity (running, cycling)*" in their 1995 study and 3-5 hours per week of "*resistance training and aerobic activity*" for the athletes in their 1997 study. Swimmers and water polo athletes in the current study were resistance training 2-3 days per week for approximately one hour, performing multi-joint, core exercises such as squats, deadlifts, pull-ups, bent-over rows, and bench press.

We report similar bone health at the spine and whole body for runners, swimmers, water polo athletes, and controls. This contrasts with previous research that the weight-bearing nature of running may protect BMD at the hip and whole body, but not the spine (Barrack et al., 2008; Tam et al., 2018). Female distance runners were found to have significantly greater BMD than controls, displaying an advantage in bone mass, especially of the whole body (McCormack et al., 2019). However, some research shows that running may be beneficial to bone health in college-age males but not females (Infantino et al., 2021). Runners frequently exhibit lower than expected bone mass and increased risk for fractures when practicing dietary restraint or when energy availability is lacking (Barrack et al., 2008; Fredericson et al., 2007; McCormack et al., 2019; Tenforde et al., 2018; Tenforde et al., 2015). The current investigation could be strengthened by including analysis of energy availability.

Runners in this study were consuming significantly more calcium than the other groups and achieving more the recommended dietary allowance (RDA) of 1000 mg per day (IOM, 2011). On average, swimmers were consuming 41% of the RDA, water polo athletes 63%, and controls 88%. Calcium intake was used as a covariate in this analysis, since it was significantly different between groups and correlated to BMD at the whole body ($r = 0.303$, $p = .004$). Adequate consumption of calcium is vital to achieving optimal peak bone mass in addition to meeting the physical demands of sport (Sale and Elliott-Sale, 2019; Weaver et al., 2016). While the benefit of calcium on bone health is well established, some research indicates that high impact exercise is more important than dietary calcium for building bone strength (Welch et al., 2008). Thus, comprehensive analysis of bone health includes assessment of dietary intake and weight-bearing physical activity. Aquatic athletes in this study may benefit from increasing dietary calcium intake.

A strength of this study is the examination of water polo athletes which widens the population of non-weight-bearing athletes, providing more depth to the data compared to previous studies which only assessed swimmers. As a newer collegiate sport in the USA, there is less research involving water polo players and this study contributes to building up the literature. The non-weight-bearing environment in aquatic sports is similar but stresses the body in different ways which could contribute to the differences in bone health observed here between swimmers and water polo players. This study also emphasizes evaluation of multiple (six) bone sites for a comprehensive evaluation of bone health throughout the skeleton. In future investigations, it would be beneficial to increase the sample size of the study to provide a more generalizable view of bone health in different sports. Longitudinally our study did not have a high number of participants which makes it difficult to extrapolate the findings. Further, analysis of musculoskeletal injuries and serum levels of vitamin D would also provide a better understanding of holistic bone health.

CONCLUSIONS

In summary, we report that bone health in female aquatic athletes was similar to controls and runners, except at the FN where BMD of swimmers was less than water polo players. These findings are somewhat contradictory to work from the 1990s that reported lower BMD in aquatic athletes, even in comparison to non-athletes. Perhaps modern approaches to training for female collegiate athletes leads to similar bone health even in sports with different skeletal impact. Of the three groups of athletes, swimmers were the only ones to display significant increases in bone health over 5 months of training.

AUTHOR CONTRIBUTIONS

All authors were involved with study conceptualization, data curation, analysis, funding acquisition, investigation, and methodology. EK and HA wrote the original draft, reviewed, and edited this paper. All authors read and approved the final version of the manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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