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Systematic Review

Participation in Elite Sport in Youth and Its Impact on Lifelong Bone Health

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Abstract: Weight-bearing physical activity is considered beneficial to bone health throughout the course of life, with the most marked benefits for bone health often considered to be high levels of activity around the time of peak bone mass (PBM) acquisition. To date, the research focus has been on the benefits of recreational weight-bearing sporting activity. Participation in elite sport is associated with enhanced sporting activity but is often also associated with low body weight, menstrual disturbance in females, and rest periods following injury. The benefit of sporting activity may, therefore, be attenuated in these groups. Here, we undertook a systematic review to consider what evidence is available regarding whether elite sporting activity in young adulthood has lasting benefits for bone health. Studies of retired athletes aged >50 years, who participated in elite sport from 15 to 30 years, were considered for inclusion. Elite sport was defined as participation at the national level or above. Following protocol development, the search strategy was applied to PubMed, Medline, Embase, and Web of Science. The selection was managed with Rayyan software, and the bias was assessed using the Newcastle–Ottawa scale. Two reviewers independently identified papers; a third adjudicated and screened the final selection for consideration. The protocol was registered with PROSPERO (CRD42021293644). Two reviewers screened 951 articles, of which 4 papers met the inclusion criteria. One paper reported findings in women and three in men; no paper included both sexes. The sample sizes varied from 24 to 193 and considered football, endurance running, weightlifting, and swimming. Bone density was measured at the femoral neck, trochanter, and lumbar spine. All studies reported higher density in former athletes than non-elite controls, though the information available regarding confounding lifestyle factors was variable. A meta-analysis was not possible as studies were too heterogenous. In conclusion, from the limited available evidence, our study suggests elite sporting activity in young adulthood may have lasting benefits for bone health. However, given the paucity of available data, we highlight an urgent need for future research, especially in female athletes.

Keywords: bone density; elite sport; peak bone mass

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1. Introduction

Osteoporosis represents a major public health burden through its association with morbidity and mortality and associated financial implications [1]. Peak bone mass is a major determinant of later fracture risk [2]; bone mass acquisition (BMA) occurs largely in childhood and adolescence, notably during puberty, and continues until approximately the third decade when it declines in the fifth decade [3]. Eighty percent of BMA is attributable to genetic factors and 20% to environmental factors including diet and exercise [3].

Participation in sport and exercise is typically expected to have positive effects on bone mineral density (BMD). Studies have consistently shown sport (especially weight-bearing activities) positively influences BMD [4,5]. Mechanical loading promotes bone osteoblast proliferation and bone accrual; hence, walking or running increases BMD more than non-weight-bearing activities such as swimming [6]. A mixed frequency and magnitude of loading provide the optimal osteogenic response, and while low-frequency impact and resistance movements do not reach the osteogenic stimulation threshold, high-frequency and low-magnitude sports overstimulate the bone; both can result in maladaptation [7]. For this reason, the characteristics of sport participation are thought to be important when considering likely positive effects. Overall, however, benefits appear likely from recreational habitual sporting activity as suggested by a recent systematic review, although this review used calcaneal heel ultrasound as an outcome [8]. The evidence of persisting benefit from physical activity during the age of peak bone mass acquisition typically comes from retrospective studies reporting recalled sporting activity in youth [9,10].

When comparing the level of sporting activity, one's participation in elite sport over adolescence and young adulthood may be expected to have even greater benefits on bone mineral accrual if such participation includes a high level of physical loading. However, overtraining, low BMI, and oligomenorrhoea in women are often associated with adverse bone events, including stress fractures [11]. There have also been suggestions that puberty timing can be delayed by intense training [12]. The aim of this study was, therefore, to consider what the research literature reports on bone health outcomes in former elite athletes, specifically to test a hypothesis that bone health would be better in this group, despite the association of elite sporting activity with factors associated with poor bone health, including amenorrhoea and low body mass index.

2. Methods

This systematic review was registered with PROSPERO, CRD42021293644. Table 1 and Figure 1 describe the search strategy for this systematic review. The online electronic research databases included were PubMed (National Library of Medicine), Medline (OVID), EMBASE (OVID), and the Web of Science Core Collection (Clarivate); see Table 1. The trial and final searches were completed by April 2023. Only English-language texts were considered. All papers retrieved were transferred to the online intelligent systematic review software, Rayyan, to be screened individually by two reviewers (A.M. + F.K.W.). A third individual (E.D.) aided in the final paper inclusions. The selection was performed closely with our inclusion and exclusion criteria; see Table 2. All stages were noted alongside the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) format [13].

Table 1. Summary of the search terms.

Medline (OVID): (athlete/ OR athlete* OR sports*) AND (elite OR professional) AND (bone adj3 (dens* OR content* OR measure*) AND (adult OR middle aged OR aged OR later life OR masters OR longevity/ OR "life span")
Embase: (athlete/ OR athlete* OR sports*) AND (elite OR professional) AND (bone adj3 (dens* OR content* OR measure*) AND (adult OR middle aged OR aged OR later life OR masters OR longevity/ OR "life span")
PubMed: (athlete/ OR athlete* OR sports*) AND (elite OR professional) AND ("bone mineral dens*" OR bone mineral content*" OR "bone mineral measure*" OR "bone dens*" OR "bone content*" OR "bone measure*") AND (adult OR middle aged OR aged OR later life OR masters OR longevity/ OR "life span")
Web of Science: (athlete/ OR athlete* OR sports*) AND (elite OR professional) AND ("bone mineral dens*" OR bone mineral content*" OR "bone mineral measure*" OR "bone dens*" OR "bone content*" OR "bone measure*") AND (adult OR middle aged OR aged OR later life OR masters OR longevity/ OR "life span")

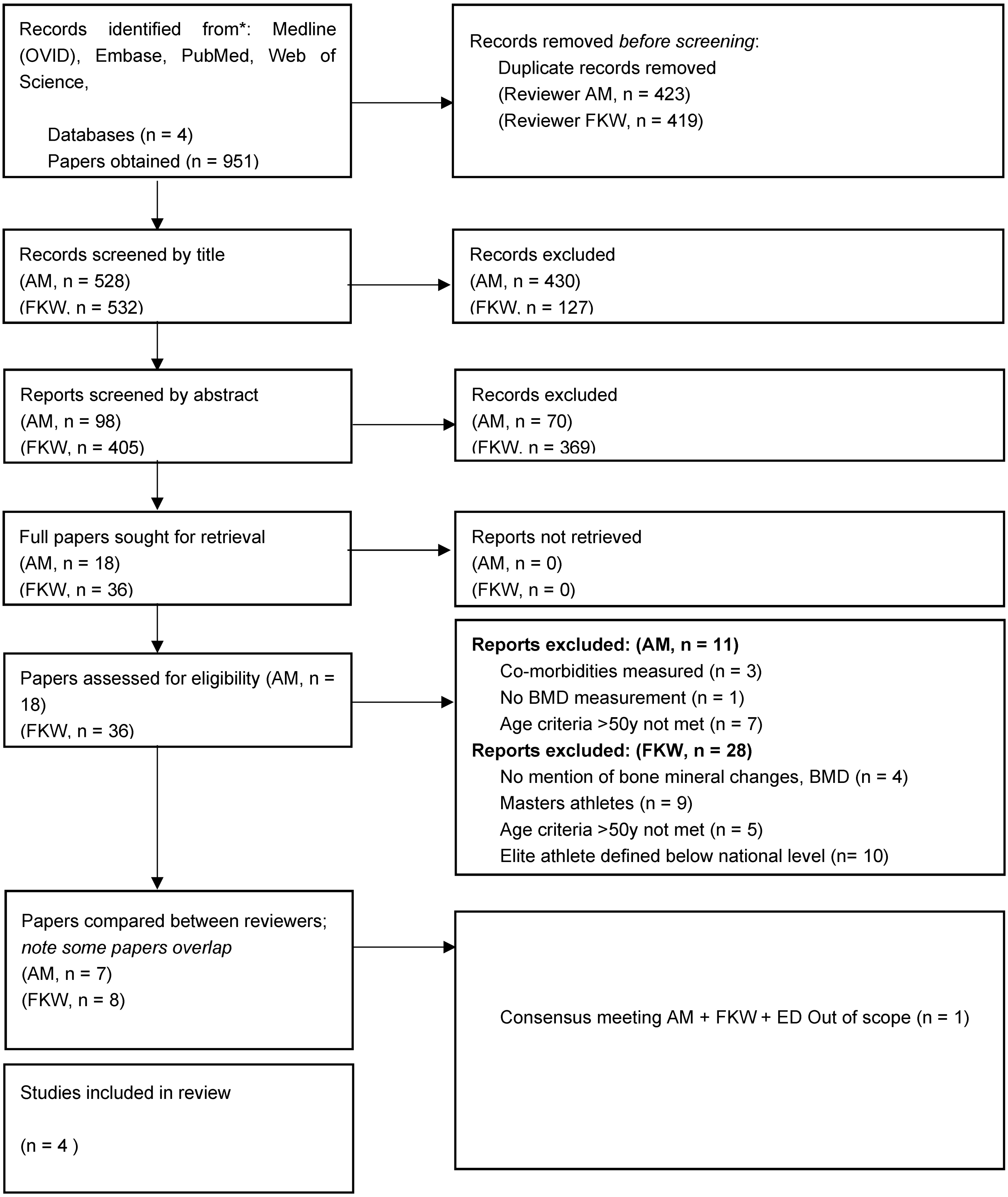

Figure 1. PRISMA flowchart of the literature paper search and the selection process. **BMD** = bone mineral density.

Table 2. Screening of papers according to PICO format.

1.	**Population**	**Inclusion criteria:** adults aged >50 years who have partaken in elite sport in young adulthood aged 15–30 years. This study includes both sexes (human only) and 'elite' is described as national level or above.
		Exclusion criteria: individuals with chronic health conditions, including disabilities (physical and mental) which have impacted bone health or sport. Participation up to the regional level was excluded. Master athletes were excluded. Elite athletes who started the sport >30 years of age.
2.	**Intervention(s)**	Retired athletes who partook in elite sporting activity in young adulthood.
3.	**Comparator(s)**	Controls, with no history of participation in elite sport. Level of activity was not limited. All permitted were matched with athletes in terms of age and sex.
4.	**Outcome(s)**	Bone mineral density.

Our primary outcome was BMD at age >50 years among individuals who had participated in elite sport during peak bone mass acquisition. We followed STROBE (Strengthening The Reporting of Observational Studies) guidelines [14], and observational studies were included. A meta-analysis was not performed as the data were too heterogenous. Bias was assessed using the Newcastle–Ottawa quality assessment scoring system [15]. Considering the following domains, a point was granted for each of the following points:

1. *Study group selection*
   a. Adequate case definition?
   b. Do participants represent the case hypothesis?
   c. Control selection process: from community?
   d. Control criteria: any limiting factors?
2. *Comparability of participant groups*
   a. Strong confounders
   b. Review of the outcome
3. *Exposure*
   a. Blinded/non-blinded?
   b. Same methods in all participant groups?
   c. Non-response rate (if applicable)?

3. Results

In total, 951 articles were retrieved from four databases. Two reviewers undertook independent screening, detailed in Table 2. Papers were screened in three steps: elimination by title, then abstract, then full paper review. A third reviewer was consulted to confirm the final papers for inclusion; three were agreed upon between reviewers 1 and 2 and 5 further papers were discussed at a consensus meeting with a third reviewer agreeing that one further paper be included. The literature appraisal was performed using the Newcastle–Ottawa scale [15]; see Table 3. All studies were deemed to be low-bias and have a sufficient declaration of hypotheses, transparency regarding limitations, and well-matched controls. These were observational studies, so blinded status was not applicable.

Table 4 displays the key findings from the four papers included [16–19], of which only one studied female athletes. In all studies, reported BMD was greater in retired athletes compared to controls, though differences were less marked in the oldest former athletes [18]. However, there were considerable limitations in the data available. The size of the studies varied considerably, limiting the power to study associations, with one study having only 24 participants in each group [18]. All studies compared former elite athletes with non-athletic controls who were engaged in variable levels of recreational sport, and a wide range of sports were considered (football, endurance running, weightlifting, and swimming). Of note, one study [18] reported findings in regard to both BMD and fracture; only the first was considered in this review.

Table 3. Quality assessment of selected papers.

Newcastle–Ottawa Screening Tool		Kettunen J. et al. (2010) [16]	Andreoli A. et al. (2012) [17]	Tveit M. et al. (2015) [18]	Lv H. et al. (2018) [19]
Study group comparison	Adequate case definition?	Y	Y	Y	Y
	Do participants represent the case hypothesis?	Y	Y	Y	Y
	Control selection process: from the community?	Y	Y	Y	Y
	Control criteria: any limiting factors?	-	N	N	N
Comparability of the participant groups	Strong confounders?	Y	Y	Y	Y
	Review of the outcome?	Y	Y	Y	Y
Exposure	Blinded?	N	N	N	N
	Same methods for both participant groups?	Y	Y	Y	Y
	Sufficient response rate?	N	Y	Y	Y
Scoring 0–9		6	8	8	8

Y = yes, **N** = no, **-** = not applicable.

Table 4. Study characteristics from the selected literature.

Author (Year)	**Kettunen J. et al. (2010) [16]**	**Andreoli A. et al. (2012) [17]**	**Tveit M. et al. (2015) [18]**	**Lv H. et al. (2018) [19]**
Journal	*Bone*	*European Journal of Clinical Nutrition*	*Scandinavian Journal of Medicine & Science in Sports*	*International Orthopaedics*
Type of study	Case–control	Case–control	24 Caucasian female ex-athletes	12 runners, 12 swimmers
Athlete population size	87 male ex-athletes (2147 contacted)	Cross-sectional cohort study	* 193 retired male elite soccer players	193 footballers
Sport(s)	31 football, 28 endurance running, 28 weight-lifting	Cross-sectional descriptive study	86 retired male professional football players	86 footballers
Controls	194 male controls	24 Caucasian female controls	280 controls	86 controls
Bone measurement sites	DEXA; FN, FT **	DEXA; LA, RA, LS **	DEXA; TB, A, L, LS, FN **	DEXA; FN, FT, spine **
Key results	Athletes (soccer, endurance, and weight-lifters) had a mean significantly higher BMD at both FN and FT than controls. Once adjusted for BMI and age, the *p* value was <0.0002	BMD and BMC were higher in both groups (swimmers and runners) than controls, $p < 0.01$	BMD is greater in both age groups > 50 years ($p < 0.001$). BMD becomes more similar between data groups at the 69 average age sub-group (*p* 0.02).	A greater BMD has a positive impact on reduced knee osteoarthritis risk + improved knee function ($p < 0.001$).

* Note: only the groups > 50 years are included for the purpose of this review. ** **DEXA** = dual x-ray absorptiometry, **A** = arms, **LA** = left arm, **RA** = right arm, **L** = legs, **LL** = left leg, **RL** = right leg, **S** = spine, **TB** = total body, **A** = arm, **L** = leg, **FN** = femoral neck, **FT** = femoral trochanter, **LS** = lumbar spine, **BMD** = bone mineral density, **BMC** = Bone mineral content.

The key data extracted can be viewed in Table 5. All participants were in their sixth and seventh decades; all four studies reported highly significant differences in BMD between cases and controls, with higher values reported in former athletes. While studies often reported differences in bone health between different categories of sporting activity, it was hard to draw meaningful conclusions in light of the limitations discussed above. For example, one study reported the highest BMD values in former footballers but numbers in each group were low and age matching was sub-optimal [16]. Another study reported higher spinal BMD in runners relative to elite swimmers and controls [17]. The duration of retirement was studied in one study [18], where differences between former elite athletes and controls became less marked with time.

Table 5. Key bone measurement data from the selected literature.

Author (Year)	Relevant Data Extracted				
Kettunen J. et al. (2010) [16]	**Athletes** n = 87			**Controls**	**Significance**
	Football (n = 31)	Endurance running (n = 28)	Weightlifting (n = 28)	n = 194	$p < 0.0002$
	Average age = 56.5	Average age = 59.7	Average age = 59.2	Average age = 55.8	
	FN = 1.032 (SD 0.163), **FT** 0.969 (SD 0.131)	**FN** = 0.977 (SD 0.145), **FT** = 0.885 (SD 0.128)	**FN** = 0.962 (SD 0.191), **FT** = 0.908 (SD 0.169)	**FN** = 0.905 (SD 0.131), **FT** = 0860 (SD 0.121)	
Andreoli A. et al. (2012) [17]	**Athletes**			**Controls**	**Significance**
	n = 12 runners	n = 12 swimmers		n = 24	$p < 0.01$
	Average age = 57.8	Average age = 58.4		Average age = 60.8	
	LA = 0.692 (SD 0.074), **RA** = 0.716 (SD 0.088), **LS** = 1.162 (SD 0.198), **LL** = 1.130 (SD 0.144), **RL** = 1.115 (SD 0.138)	**LA** = 0.703 (SD = 0.057), **RA** = 0.710 (SD 0.063), **LS** 0.938 (SD 0.0164), **LL** = 1.043 (SD 0.099), **RL** = 0.942 (SD 0.112)		**LA** = 0.640 (SD 0.068), **RA** = 0.647 (SD 0.068), **LS** = 0.938 (SD 0.164), **LL** 0.921 (SD = 0.107), **RL** = 0.942 (SD 0.112)	
Tveit M. et al. (2015) [18]	**Athletes**			**Controls**	**Significance**
	n = 48 Average age = 57.27 *(retired for 20–29 years)*			n = 157 Average age = 53.85	$p < 0.001$ to 0.44
	TB = 1.23 (SD 0.07), **A** 0.97 (SD 0.06), **L** 1.40 (SD 0.10), **LS** 1.26 (SD 0.12), **FN** = 0.96 (SD 0.11)			**TB** = 1.18 (SD 0.08), **A** = 0.95 (SD 0.08), **L** 1.30 (SD 0.10), **LS** = 1.18 (SD 0.19), **FN** = 0.94 (SD 0.12)	
	n = 83; Average age = 69.14 *(retired for >30 years)*			n = 141; Average age = 69.01	p 0.002 to 0.66
	TB = 1.19 (SD 0.10), **A** = 0.92 (SD 0.08), **L** 1.32 (SD 0.13), **LS** = 1.25 (SD 0.22), **FN** = 0.91 (SD 0.16)			**TB** = 1.16 (SD 0.09), **A** = 0.92 (SD 0.10), **L** = 1.27 (SD 0.12), **LS** = 1.18 (0.22), **FN** = 0.90 (SD 0.14)	
Lv H. et al. (2018) [19]	**Athletes**			**Controls**	**Significance**
	n = 86			n = 86	$p < 0.001$
	Average age = 53			Average age = 52	
	FN = 0.913 (SD 0.254), **FT** = 0.860 (SD 0.177)), **S** = 0.921 (SD 0.098)			**FN** = 0.638 (SD 0.176), **FT** = 0.624 (SD 0.235), **S** = 0.720 (SD 0.099)	

A = arms, **LA** = left arm, **RA** = right arm, **L** = Legs, **LL** = left leg, **RL** = right leg, **S** = spine, **TB** = total body, **A** = arm, **L** = leg, **FN** = femoral neck, **FT** = femoral trochanter, **LS** = lumbar spine, **SD** = standard deviation.

4. Discussion

The aim of this study was to review the available literature that considered the association between participation in elite sport during the time of peak bone mass acquisition and later bone density. Only four studies, published in the last 13 years, were identified in this systematic review that considered bone health in former elite athletes with a mean age of 57.4 years. Taken together, we found evidence that elite sport in young adulthood does have a lasting benefit for bone health, although confounded by the maintenance of a physically active lifestyle in former athletes seems likely and highlights the need for longitudinal follow-up with this group. Longitudinal studies of an appropriate duration seem especially important given one included study that suggested that differences in bone health between former elite athletes and controls became less marked with time [18]. Overall, the lack of available literature was striking, particularly regarding females.

One important aspect of bone health in female former elite athletes is that of oligomenorrhoea due to low BMI at the time of peak bone mass acquisition [11]. Only one study included in this systematic review considered female former athletes, where only eumenorrheic athletes (when young) were considered, reducing the risk of menstrual status influencing bone health [17]. Hence, further research in this area is urgently required. There are also reasons why male former elite athletes may not enjoy better bone health in late adulthood. Relative energy deficiency in sport (RED-S), a common phenomenon, can be detrimental to improvement and overall health in sport [20], which may negatively impact BMD in both sexes [21]. Energy availability has shown correlations with vitamin D levels, which may be relevant for bone health [22]. Low BMD is a risk factor for stress fractures, a particular risk for elite athletes of either sex whose careers may be ended prematurely as a result of injury [23,24].

Our own review focuses on adults >50 years who participated in elite sporting activity over the time of peak bone mass acquisition. Nordström and colleagues considered BMD in athletes who played competitively, with bone density figures from before and after retirement [25]. The average age of participants was between 25.3 and 27.3 years, well within the scope of peak BMA. This was compared against non-athletic controls and master athletes (elite athletes older than 35). They found that former athletes did lose bone after retirement but did record higher bone density than controls after 5 years of follow-up.

We would normally expect weight-bearing activity to be associated with higher bone mass. Previous systematic reviews of bone health in swimmers studied at the time of peak bone acquisition suggest that swimmers would not be expected to have higher BMD than controls or other athletes [26]. Hence, the finding in one study included in this systematic review, which was made up of only 24 participants including 12 runners and 12 swimmers, may reflect a chance finding. It may also reflect other lifestyle factors in this group of former athletes, including activity profile post-retirement from sport or nutritional factors.

There are several limitations in the available data. Participants were matched according to age, sex, and BMI with athletes in three papers [17–19]; however, Kettunen et al. noted a difference in age between the former athletes studied and the control group, which limits the interpretation of the findings [16]. All controls selected had no elite sporting background but varying activity levels. Ex-athletes could be more likely to remain active due to habitual routines—thereby continuing to gain benefits from bone loading—but this could not be disentangled here. Different sports may influence bone accrual and loss at varying levels, but the lack of studies prevented a clear discussion of this point. Although we would have liked to present data on T/Z scores across the populations for ease of comparison, these were only available for two of four of the studies. A meta-analysis could not be performed as the exposure population was too diverse. Athletes who suffered from injuries were not included. Importantly, we have not included master athletes in this review. Our findings relate to participation in elite sport only at the time of peak bone acquisition with retirement shortly thereafter. We acknowledge that activity profiles are likely to differ in elite athletes post-retirement when compared with the general public, and this is an important limitation when interpreting results and planning further studies, which should include the careful collection of data regarding this point.

While some studies have suggested that elite sport participation may have contemporaneous benefits for bone health [22,27–29], this review has highlighted the paucity of research data available regarding this important topic. Longitudinal studies are required, with consideration given to menstrual status in females and vitamin D status in all athletes. This is an important issue given the importance of osteoporosis prevention to public health, and more robust data are needed to determine the risk-to-benefit ratio of high-level sport. Elite sport can have lasting benefits but there is also a higher risk of injury and overtraining, with associated detrimental impacts, both to one's career and also longer-term health, including bone health.

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References

1. Drinkwater, L.; Goldsmith, R.S.; Conrad Johnston JrC, L.R.; Mack, T.M.; Meunier, P.J.; Christopher Nordin, B.E.; Michael Parfitt, A. Consensus development conference: Prophylaxis and treatment of osteoporosis. *Br. Med. J.* **1987**, *295*, 914–915.
2. Johnell, O.; Kanis, J. Epidemiology of osteoporotic fractures. *Osteoporos. Int.* **2005**, *16*, S3–S7. [CrossRef] [PubMed]
3. Holroyd, C.; Cooper, C.; Dennison, E. Epidemiology of osteoporosis. *Best Pract. Res. Clin. Endocrinol. Metab.* **2008**, *22*, 671–685. [CrossRef] [PubMed]
4. Oliveira, T.P.; Espada, M.C.; Massini, D.A.; Robalo, R.A.; Almeida, T.A.; Hernández-Beltrán, V.; Gamonales, J.M.; Castro, E.A.; Pessôa Filho, D.M. Effects of Exercise and Sports Intervention and the Involvement Level on the Mineral Health of Different Bone Sites in the Leg, Hip, and Spine: A Systematic Review and Meta-Analysis. *Int. J. Environ. Res. Public Health* **2023**, *20*, 6537. [CrossRef]
5. Cui, W.; Li, D.; Jiang, Y.; Gao, Y. Effects of exercise based on ACSM recommendations on bone mineral density in individuals with osteoporosis: A systematic review and meta-analyses of randomized controlled trials. *Front. Physiol.* **2023**, *14*, 1181327. [CrossRef] [PubMed]
6. Andreoli, A.; Monteleone, M.; Van Loan, M.; Promenzio, L.; Tarantino, U.; De Lorenzo, A. Effects of different sports on bone density and muscle mass in highly trained athletes. *Med. Sci. Sports Exerc.* **2001**, *33*, 507–511. [CrossRef] [PubMed]
7. Hart, N.H.; Nimphius, S.; Rantalainen, T.; Ireland, A.; Siafarikas, A.; Newton, R.U. Mechanical basis of bone strength: Influence of bone material, bone structure and muscle action. *J. Musculoskelet. Neuronal Interact.* **2017**, *17*, 114. [PubMed]
8. Patel, H.; Sammut, L.; Denison, H.; Teesdale-Spittle, P.; Dennison, E. The relationship between non-elite sporting activity and calcaneal bone density in adolescents and young adults: A narrative systematic review. *Front. Physiol.* **2020**, *11*, 505019. [CrossRef] [PubMed]
9. Zhang, J.; Parsons, C.; Fuggle, N.; Ward, K.A.; Cooper, C.; Dennison, E. Is regular weight-bearing physical activity throughout the lifecourse associated with better bone health in late adulthood? *Calcif. Tissue Int.* **2022**, *111*, 279–287.
10. Khan, K.; McKay, H.A.; Haapasalo, H.; Bennell, K.L.; Forwood, M.R.; Kannus, P.; Wark, J.D. Does childhood and adolescence provide a unique opportunity for exercise to strengthen the skeleton? *J. Sci. Med. Sport* **2000**, *3*, 150–164.
11. Ackerman, K.E.; Misra, M. Bone health and the female athlete triad in adolescent athletes. *Physician Sportsmed.* **2011**, *39*, 131–141. [CrossRef] [PubMed]
12. Kapczuk, K. Elite athletes and pubertal delay. *Minerva Pediatr.* **2017**, *69*, 415–426. [CrossRef] [PubMed]
13. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ* **2021**, *372*, n71. [CrossRef] [PubMed]
14. Vandenbroucke, J.P.; von Elm, E.; Altman, D.G.; Gøtzsche, P.C.; Mulrow, C.D.; Pocock, S.J.; Poole, C.; Schlesselman, J.J.; Egger, M. Strengthening the reporting of observational studies in epidemiology (STROBE). *Epidemiology* **2007**, *18*, 805–835. [CrossRef]
15. Wells, G.; Shea, B.; O'Connell, D.; Robertson, J.; Peterson, J.; Welch, V.; Losos, M.; Tugwell, P. The Newcastle-Ottawa scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. *Ott. Hosp. Res. Inst.* **2011**, *2*, 1–12.
16. Kettunen, J.A.; Impivaara, O.; Kujala, U.M.; Linna, M.; Mäki, J.; Räty, H.; Alanen, E.; Kaprio, J.; Videman, T.; Sarna, S. Hip fractures and femoral bone mineral density in male former elite athletes. *Bone* **2010**, *46*, 330–335. [CrossRef] [PubMed]

17. Andreoli, A.; Celi, M.; Volpe, S.L.; Sorge, R.; Tarantino, U. Long-term effect of exercise on bone mineral density and body composition in post-menopausal ex-elite athletes: A retrospective study. *Eur. J. Clin. Nutr.* **2012**, *66*, 69–74. [CrossRef] [PubMed]
18. Tveit, M.; Rosengren, B.E.; Nilsson, J.Å.; Karlsson, M.K. Exercise in youth: High bone mass, large bone size, and low fracture risk in old age. *Scand. J. Med. Sci. Sports* **2015**, *25*, 453–461. [CrossRef] [PubMed]
19. Lv, H.; Chen, W.; Yuwen, P.; Yang, N.; Yan, X.; Zhang, Y. Multivariate analysis of factors related to radiographic knee osteoarthritis based on the comparison between football players and matched nonsportsmen. *Int. Orthop.* **2018**, *42*, 519–527. [CrossRef]
20. Heikura, I.A.; Uusitalo, A.L.; Stellingwerff, T.; Bergland, D.; Mero, A.A.; Burke, L.M. Low energy availability is difficult to assess but outcomes have large impact on bone injury rates in elite distance athletes. *Int. J. Sport Nutr. Exerc. Metab.* **2018**, *28*, 403–411. [CrossRef]
21. Tam, N.; Santos-Concejero, J.; Tucker, R.; Lamberts, R.P.; Micklesfield, L.K. Bone health in elite Kenyan runners. *J. Sports Sci.* **2018**, *36*, 456–461. [CrossRef]
22. Andersen, O.K.; Clarsen, B.; Garthe, I.; Mørland, M.; Stensrud, T. Bone Health in Elite Norwegian Endurance Cyclists and Runners: A Cross-Sectional Study. *Med. Sci. Sports Exerc.* **2019**, *51*, 679. [CrossRef]
23. Tenforde, A.S.; Fredericson, M. Influence of sports participation on bone health in the young athlete: A review of the literature. *PM&R* **2011**, *3*, 861–867.
24. Myburgh, K.H.; Hutchins, J.; Fataar, A.B.; Hough, S.F.; Noakes, T.D. Low bone density is an etiologic factor for stress fractures in athletes. *Ann. Intern. Med.* **1990**, *113*, 754–759. [CrossRef]
25. Nordström, A.; Karlsson, C.; Nyquist, F.; Olsson, T.; Nordström, P.; Karlsson, M. Bone loss and fracture risk after reduced physical activity. *J. Bone Miner. Res.* **2005**, *20*, 202–207. [CrossRef]
26. Gomez-Bruton, A.; Montero-Marín, J.; González-Agüero, A.; Gómez-Cabello, A.; García-Campayo, J.; Moreno, L.A.; Casajús, J.A. Vicente-Rodríguez G. Swimming and peak bone mineral density: A systematic review and meta-analysis. *J. Sports Sci.* **2018**, *36*, 365–377.
27. Imeri, B.; Gheitasi, M.; Khaledi, A.; Mozafaripour, E. Bone Mineral Density and Content among Iranian Elite Male Athletes in Different Sports. *Arch. Bone Jt. Surg.* **2023**, *11*, 212–217.
28. Hagman, M.; Helge, E.W.; Fristrup, B.; Jørgensen, N.R.; Helge, J.W.; Krustrup, P. High bone mineral density in lifelong trained female team handball players and young elite football players. *Eur. J. Appl. Physiol.* **2021**, *121*, 2825–2836. [CrossRef]
29. Bellver, M.; Del Rio, L.; Jovell, E.; Drobnic, F.; Trilla, A. Bone mineral density and bone mineral content among female elite athletes. *Bone* **2019**, *127*, 393–400. [CrossRef]