Soccer helps build strong bones during growth: a systematic review and meta-analysis

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Abstract

The aim of this study was to analyze the effects of soccer practice on bone in male and female children and adolescents. MEDLINE, PubMed, SPORTDiscus and Web of Science databases were searched for scientific articles published up to and including October 2016. Twenty-seven studies were included in this systematic review (13 in the meta-analysis). The meta-analysis was performed by using OpenMeta[Analyst] software. It is well documented that soccer practice during childhood provides positive effects on bone mineral content (BMC) and density (BMD) compared to sedentary behaviors and other sports, such as tennis, weightlifting, or swimming. Furthermore, soccer players present higher BMC and BMD in most weight-bearing sites such as the whole body, lumbar spine, hip, and legs. Moreover, bone differences were minimized between groups during prepuberty. Therefore, the maturity status should be considered when evaluating bone. According to meta-analysis results, soccer practice was positively associated with whole-body BMD either in males (mean difference 0.061; 95%CI, 0.042–0.079) or in females (mean difference 0.063; 95%CI, 0.026–0.099).

Conclusion: Soccer may be considered a sport that positively affects bone mass during growth. Pubertal soccer players presented increased bone mass compared to controls or other athletes; however, these bone differences are minimized during the prepubertal stage.

What is known:

• *It has been described that childhood and adolescence are important*

periods for bone mass and structure.
• Previous studies have demonstrated that soccer participation improves bone mass in male and female children and adolescents.

What is new:
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• The present study reinforced that bone mass is positively stimulated by soccer practice during growth.
• The differences between soccer players and controls are more marked during puberty than prepuberty.
• Weight-bearing sites such as lumbar spine, hip, femoral neck, trochanter, intertrochanteric region and both legs are particularly sensitive to soccer actions.

Keywords

Football
Sports
Bone mass
Bone tissue

Abbreviations

BMC	Bone mineral content
BMD	Bone mineral density
DXA	Dual-energy X-ray absorptiometry
pQCT	Peripheral quantitative computed tomography
QUS	Quantitative ultrasound system
SPA	Single photon absorptiometry
WHO	World Health Organization

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Electronic supplementary material

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Introduction

Osteopenia and osteoporosis are important diseases worldwide and are characterized by low bone mineral density (BMD) and microarchitectural deterioration [4]. These diseases appear mainly in the elderly causing morbidity, mortality, and high economic costs to society [8]. Nevertheless, childhood and adolescence have been described as critical periods to counteract them because 26% of the adult bone mineral content (BMC) is accumulated at the ages of approximately 12 and 14 years in females and males [5], respectively. Thus, appropriate bone mass accretion during growth seems fundamental to reduce the risk of suffering bone fractures in advanced age [32].

Both BMC and BMD are mainly determined by genetics [1]; nevertheless, lifestyle factors such as physical exercise [42] and nutrition [15] can also influence them. However, not all factors have the same relevance in this regard [45]; and similarly, not all physical exercises or sports have equal repercussions on bone tissue [38]. Different sport classifications have been proposed as follows according to their osteogenic stimulus: high/odd /repetitive/low-impact sports [26] or weight-bearing/non-weight-bearing sports [21]. Cycling and swimming are classified as non-weight-bearing sports, while others such as gymnastics or soccer are classified as high-impact sports [38].

Bone improvements are strongly correlated with high-impact and weight-bearing sports but not as correlated with non-weight-bearing ones. A continued practice of a high-impact sport such as soccer during growth could help to maintain these improvements and to attain high BMC and BMD [38].

Several studies have reported positive effects of soccer participation on bone mass either in male or in female children and adolescents [12, 28, 43, 49]; however, some authors such as Zouch et al. [48] and Seabra et al. [34] have not demonstrated this positive effect of soccer on bone mass. On the other hand, only one study is focused on gender differences during childhood or adolescence [21].

Therefore, the aim of this systematic review and meta-analysis was to investigate the effects of soccer practice on bone mass in both genders and different pubertal stages in children and adolescents.

Materials and methods

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Data sources and search strategy

This review has been performed following the criteria and methodology established by the Preferred Reporting Items for Systematic reviews and Meta-Analyses Protocols (PRISMA-P) 2015 statement [22].

Journal articles were identified by searching in electronic databases and scanning references and lists of articles. The search strategy was applied to MEDLINE, PubMed, SPORTDiscus, and Web of Science up to and including October 2016.

The search strategy used to identify the articles in MEDLINE was as follows: (“Soccer”[Mesh] AND (“Bone Density”[Mesh] OR “Bone and Bones”[Mesh])) NOT “Soccer/injuries”[Mesh]. Moreover, “Humans” and “Child: birth-18 years” filters were applied. The search strategy used in PubMed was as follows: ((Soccer[Title/Abstract] OR Football[Title/Abstract]) AND (bone[Title/Abstract] AND (child*[Title/Abstract] OR adoles*[Title/Abstract] OR young[Title/Abstract] OR youth[Title/Abstract] OR *puber*[Title/Abstract] OR prepuber*[Title/Abstract]) NOT injur*[Title/Abstract]). The search strategy applied in SPORTDiscus was as follows: (Soccer[SU Subjects (Descriptors)] AND (Bone density[SU Subjects (Descriptors)] OR Bone[SU Subjects (Descriptors)])) NOT soccer injuries[SU Subjects (Descriptors)]. The search strategy used in Web of Science was as follows: ((soccer AND (“bone density” OR “bone structure” OR “bone strength”)) NOT “soccer injuries”).

Two reviewers independently evaluated all studies. Titles and abstracts were examined, and full relevant articles were obtained and assessed using the inclusion and exclusion criteria described below. Inter-reviewer disagreements were resolved by consensus, and in some cases, a third reviewer was consulted to resolve disagreements.

The inclusion criteria

Languages of studies: English and Spanish.

Types of studies: Cross-sectional, randomized, and non-randomized controlled trials and longitudinal studies researching the effects of soccer practice on bone mass.

Types of participants: male and female soccer players (age range 6–18 years).

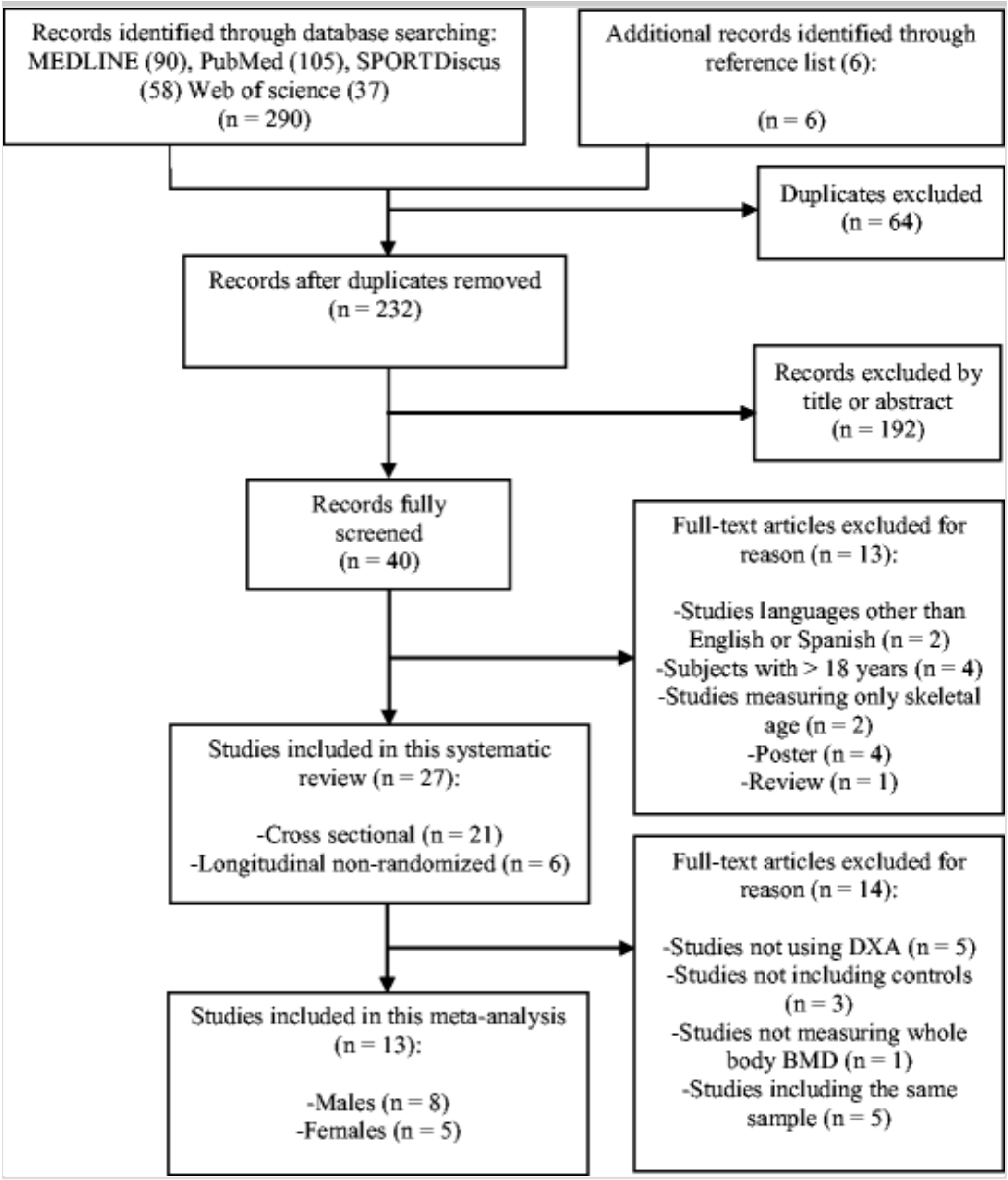
Types of outcomes: whole body, lumbar spine, leg, hip (femoral neck, trochanter, intertrochanteric region, and Ward's triangle subregions) BMC and BMD, bone architecture and ultrasound parameters (broadband ultrasound attenuation (BUA), speed of sound (SOS), and stiffness index).

The search summary

A total of 290 relevant articles were identified using the search strategies. Six additional articles were found through the reference lists. Following a review of titles and abstracts and excluding duplicates, the total number of articles was reduced to 40. Then, 27 articles met the inclusion criteria and were selected to be included in this review. On the other hand, the number of studies included in this meta-analysis, in comparison with the systematic review, were reduced from 27 to 13. Articles were excluded because of the following reasons: (1) DXA was not used [3, 7, 10, 17, 21]; (2) a control group was not included [23, 26, 40]; (3) whole-body BMD was not measured [33]; and (4) the same sample was included in different studies [12, 30, 43, 47, 48] (Fig. 1).

Fig. 1

PRISMA flow diagram of articles that were selected



The characteristics of each study included in this systematic review were summarized in different sections following PICOS format [22]: participants (P), intervention (I), comparison between groups or control group (C), outcomes (O), and study design (S).

Quality assessment

Studies were assessed using two different quality assessment tools, one for the cross-sectional studies proposed by Hinckson et al. [13] and another for the longitudinal studies proposed by Tooth et al. [39].

The first tool consisted of ten criteria that were classified in four categories (descriptive information, external validity, internal validity, and clinical effects). All of them were scored as "Yes," "No," or "Not available." Afterwards, the final score of each article was obtained by the sum of the positive answers that were classified in a specific qualitative description (0–20%, bad; 21–40%, poor 41–60%, fair; 61–80%, good; and 81–100%, excellent).

In the second quality assessment tool [39], 33 criteria were assessed, scored as "Yes," "No," or "Not available" and classified in two categories: factors that could modify the effects and descriptive elements. Then, all positive scores were summed, and the average quality score of each item and study were independently calculated. However, a specific qualitative description was not available for these scores.

Statistical analysis

Statistical analyses were performed using OpenMeta [Analyst] software (OS X version obtained from http://www.cebm.brown.edu/openmeta/). Heterogeneity between studies was assessed by chi-squared test, expressed as inconsistency index (I^2) and interpreted as follows: I^2 = 0–25% no heterogeneity, I^2 = 25–50% moderate heterogeneity, I^2 = 50–75% high heterogeneity, and I^2 = 75–100% extreme heterogeneity. BMD mean differences between soccer players and controls and their 95% confidence intervals were calculated using a continuous random-effects model (DerSimonian-Laird method) due to significant heterogeneity between studies was found.

Results and discussion

Methodological quality

Supplementary Table 1 summarizes the details of the methodological quality assessment tool for cross-sectional studies. The average quality score was 77.6% (ranged from 60 to 100); therefore, the articles included in this review can be defined as good quality. Although two studies showed poor methodological quality, they were included in this review but their conclusions should be interpreted with caution.

In longitudinal studies, the average quality score was 17.8 out of 33 (ranged from 16/33 to 19/33) (Supplementary Table 2). However, all studies were included in this review, considering that the quality assessment used was described as “very demanding” by other authors such as Tooth et al. [39] who applied this tool and showed similar results (17/33). The inclusion of this information may be of interest to enhance the quality of future longitudinal studies.

Effects of soccer practice on bone mass in children and adolescent soccer players

Due to the clear sexual dimorphism in bone development during growth [5], the outcomes of this review have been divided by gender. Tables 1 and 2 summarize studies concerning males and females. In addition, the text has been distributed according to the comparison group: controls, athletes, and among themselves.

Table 1

Effects of soccer training on bone mass in youth male soccer players

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Study	Participants			Study design	Training experience (years)	Weekl trainir (h)
	Number	Sex	Age			
McCulloch et al. [21]	SOC (23) SWI (20) CG (25)	M-F	15.3 ± 0.8 15.0 ± 1.1 14.9 ± 0.6	Cross-sectional	NA	10 18
Vicente-Rodriguez et al. [44]	SOC (53) CG (51)	M	9.3 ± 0.2 9.3 ± 0.2	Cross-sectional	1.8 ± 0.2	At leas 3

BA bone area, *BB* basketball, *BMC* bone mineral content, *BMD* bone mineral den sectional area, *CSMI* cross-sectional moment of inertia, *CST* circular strength trai child, *DXA* dual-energy X-ray absorptiometry, *FNECK* femoral neck, *FNECK_W* neck diameter, *HOCK* hockey players, *HIS* hip strength index, *HSA* hip structural intertrochanteric region, *JUD* judo, *KAR* karate, *L2* second lumbar vertebrae, *L4* spine, *M* male, *NA* not available, *NOR* normal training, *PB* pubescent, *PPB* prepu computed tomography, *QUS* quantitative ultrasound system, *SB* subtotal body, *SC* speed of sound, *SI* stiffness index, *SPA* single photon absorptiometry, *SUM* summ *TN* tanner, *TOT* total sample, *TROCH* trochanter, *U15* under 15 years, *U17* under volleyball, *WB* whole body, *WHO* World Health Organization, *WIN* winter, *WLI* v

Study	Participants			Study design	Training experience (years)	Weekl trainir (h)
	Number	Sex	Age			
Vicente-Rodriguez et al. [43]	SOC (17) CG (11)	M	8.7 ± 0.4 9.4 ± 0.3	Longitudinal study	1.8 ± 0.2	At leas 3
Zouch et al. [47]	SOC (39): 4H (21) 2H (18) CG (13)	M	11.7 ± 0.9 10.7 ± 0.6	Longitudinal study	At least 3	(4/2)
Nebigh et al. [24]	SOC (91): TN1 (11) TN2–3 (54) TN4–5 (26) CG (61): TN1 (6) TN2–3 (38) TN4–5 (17)	M	13.3 ± 0.2 13.5 ± 0.3 13.5 ± 0.3	Cross-sectional	3.9 ± 0.8	8

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Study	Participants			Study design	Training experience (years)	Weekl trainir (h)
	Number	Sex	Age			
			12.8 ± 1.1 13.4 ± 0.5 13.3 ± 0.4			
Falk et al. [10]	CHI (90): 10–12 years SOC (26) HOCK(30) CG (34) ADO (92): 14–16 years SOC (30) HOCK (31) CG (31)	M	CHI: 11.1 ± 0.5 11.2 ± 0.8 11.1 ± 0.7 15.2 ± 0.7 15.3 ± 0.9 15.2 ± 0.7	Cross-sectional	5.4 ± 1.0 4.7 ± 1.1 7.4 ± 2.3 9.0 ± 2.1	5.6 ± 1.6 6.4 ± 1.3 6.7 ± 1.8 6.5 ± 1.6
Sanchis et al. [33]	SOC (21) TEN (25) CG (22)	M	10.3 ± 0.2 10.6 ± 0.2 10.6 ± 0.2	Cross-sectional	1.8 ± 0.2 4.1 ± 1.8	4–6

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Study	Participants			Study design	Training experience (years)	Weekl trainir (h)
	Number	Sex	Age			
Mota et al. [23]	SOC (71): U19 (12) U17 (20) U15 (39)	M	< 19 ≤ 17 ≤ 15	Cross-sectional	NA	NA
Madic et al. [17]	SOC (32) CG (30)	M	10.7 ± 0.5 11.2 ± 0.7	Cross-sectional	At least 1	10–15
Silva et al. [35]	SOC (10) SWI (12) TEN (10) CG (14)	M	14.7 ± 0.8 13.8 ± 2.5 14.1 ± 1.6 13.4 ± 2.0	Cross-sectional	At least 3	15.1 ± 0.8 17.3 ± 1.6 16 ± 0.
Seabra et al. [34]	SOC (117) CG (34)	M	13.8 ± 1.5 13.3 ± 1.3	Cross-sectional	At least 3	≈ 5

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Study	Participants			Study design	Training experience (years)	Weekl training (h)
	Number	Sex	Age			
Anliker et al. [3]	SOC (66)	M	15.1 ± 1.5	Cross-sectional	9.1 ± 2.5	10.7 ± 2.0
Zouch et al. [48]	PPB (35): SOC (22) CG (13) PB (41): SOC (26) CG (15)	M	11.9 ± 0.8 11.7 ± 0.6 12.9 ± 0.8 12.5 ± 0.6	Longitudinal study	At least 3	≈ 2–5

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Study	Participants			Study design	Training experience (years)	Weekl training (h)
	Number	Sex	Age			
Plaza-Carmona et al. [31]	HG: SOC (14) SG: SOC (14) CG (14)	M	9.4 ± 0.2 8.9 ± 0.2 9.3 ± 0.1	Cross-sectional	At least 1	At leas 3
Zouch et al. [49]	SOC (42) CG (23)	M	12.0 ± 0.8 11.7 ± 0.6	Longitudinal study	At least 3	2–5

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Study	Participants			Study design	Training experience (years)	Weekl traini (h)
	Number	Sex	Age			
Agostinete et al. [2]	SOC (18) SWI (16) BB (14) JUD (12) KAR (9) CG (13)	M	12.4 ± 1.9 13.5 ± 1.5 13.4 ± 1.2 13.1 ± 1.5 13.1 ± 1.8 11.9 ± 2.2	Longitudinal study	41.5 ± 43.8 57.1 ± 32.1 32.2 ± 22.2 47.6 ± 39.3 41.1 ± 37.4 months	NA

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Study	Participants			Study design	Training experience (years)	Weekl trainir (h)
	Number	Sex	Age			
Vlachopoulos et al. [46]	SOC (37) SWI (41) CYC (29) CG (14)	M	12.8 ± 0.9 13.4 ± 1.0 13.2 ± 1.0 12.3 ± 0.5	Cross-sectional	At least 3	10.0 ± 2.3 9.5 ± 5.1 5.1 ± 2.1 –

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Table 2

Effects of soccer training on bone mass in youth female soccer players

Study	Participants			Study design	Training experience (y)	Weekly training (h)
	Number	Sex	Age			
Soderman et al. [36]	SOC (51): ≤ 16 years (23) > 16 years (18) CG (41) ≤ 16 years (28) > 16 years (23)	F	16.3 ± 0.3 16.2 ± 1.3	Cross-sectional	8.1 ± 2.1	5.0 ± 1.7

AT artificial turf, *BA* bone area, *BB* basketball, *BMC* bone mineral content, *BMD* *CG* control group, *CSMI* cross-sectional moment of inertia, *DXA* dual-energy X-r *FHEAD* femoral head, *FNECK* femoral neck, *FS* the shaft, *HB* handball, *HI* high/ *INTROCH* intertrochanteric region, *IT* intertrochanteric, *LAC* lacrosse, *LSP* lumb narrow neck, *NN* narrow neck, *NS* not specify, *PAR* parquet, *PB* pubertal, *PPB* pr repetitive/non-impact, *RSK* rope-skipping, *RUN* runners, *SJT* sprinters, jumpers, soccer players, *SOF* softball, *SPA* single-photon absorptiometry, *SWI* swimmers, volleyball, *WB* whole body, *WTRI* wards triangle, *Z* section modulus

Study	Participants			Study design	Training experience (y)	Weekly training (h)
	Number	Sex	Age			
Pettersson et al. [28]	SOC (15) RSK (10) CG (25)	F	17.4 ± 0.8 17.8 ± 0.8 17.6 ± 0.8	Cross-sectional	8.7 ± 2.2 11.5 ± 1.7	5.1 ± 2.2 6.1 ± 3.4 0.9 ± 1.1
Bellew et al. [7]	SOC (16) SWI (29) WLI (19)	F	15.1 ± 1.2 12 ± 2.1 13.6 ± 1.3	Cross-sectional	4.9 ± 1.8 5.2 ± 2.5 5.1 ± 2.4	9.8 ± 4.0 9.7 ± 5.0 9.2 ± 4.9
Nichols et al. [26]	HI (93): SOC (22) SJT (29) SOF (15) VOL (11) TEN (10) LAC (6) RNI (68): RUN (56) SWI (12)	F	TOT 15.7 ± 1.3 HI 15.6 ± 1.2 RNI 15.6 ±	Cross-sectional	TOT 6.4 ± 3.4 HI 6.5 ± 3.4 RNI 6.1 ± 3.3	TOT 1.9 ± 0.4 HI 2.0 ± 0.4 RNI 1.9 ± 0.4

AT artificial turf, *BA* bone area, *BB* basketball, *BMC* bone mineral content, *BMD*
CG control group, *CSMI* cross-sectional moment of inertia, *DXA* dual-energy X-r
FHEAD femoral head, *FNECK* femoral neck, *FS* the shaft, *HB* handball, *HI* high/
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Study	Participants			Study design	Training experience (y)	Weekly training (h)
	Number	Sex	Age			
			1.3			
Ferry et al. [11]	SOC (32) SWI (26) CG (15)	F	16.2 ± 0.7 15.9 ± 2.0	Cross-sectional	At least 7 At least 6	10
Ferry et al. [12]	SOC (32) SWI (26) CG (15)	F	16.2 ± 0.7 15.9 ± 2.0	Longitudinal study	At least 7 At least 6	10

AT artificial turf, *BA* bone area, *BB* basketball, *BMC* bone mineral content, *BMD* *CG* control group, *CSMI* cross-sectional moment of inertia, *DXA* dual-energy X-r *FHEAD* femoral head, *FNECK* femoral neck, *FS* the shaft, *HB* handball, *HI* high/ *INTROCH* intertrochanteric region, *IT* intertrochanteric, *LAC* lacrosse, *LSP* lumb narrow neck, *NN* narrow neck, *NS* not specify, *PAR* parquet, *PB* pubertal, *PPB* pr repetitive/non-impact, *RSK* rope-skipping, *RUN* runners, *SJT* sprinters, jumpers, soccer players, *SOF* softball, *SPA* single-photon absorptiometry, *SWI* swimmers, volleyball, *WB* whole body, *WTRI* wards triangle, *Z* section modulus

Study	Participants			Study design	Training experience (y)	Weekly training (h)
	Number	Sex	Age			
Plaza-Carmona et al. [29]	SOC (10) SWI (13) CG(10)	F	8.2 ± 0.1 8.5 ± 0.1 9.7 ± 0.2	Cross-sectional	NA	2

AT artificial turf, *BA* bone area, *BB* basketball, *BMC* bone mineral content, *BMD*
CG control group, *CSMI* cross-sectional moment of inertia, *DXA* dual-energy X-r
FHEAD femoral head, *FNECK* femoral neck, *FS* the shaft, *HB* handball, *HI* high/
INTROCH intertrochanteric region, *IT* intertrochanteric, *LAC* lacrosse, *LSP* lumb
narrow neck, *NN* narrow neck, *NS* not specify, *PAR* parquet, *PB* pubertal, *PPB* pr
repetitive/non-impact, *RSK* rope-skipping, *RUN* runners, *SJT* sprinters, jumpers,
soccer players, *SOF* softball, *SPA* single-photon absorptiometry, *SWI* swimmers,
volleyball, *WB* whole body, *WTRI* wards triangle, *Z* section modulus

Study	Participants			Study design	Training experience (y)	Weekly training (h)
	Number	Sex	Age			
Ubago-Guisado et al. [41]	PPB (20): SOC (20) SWI (20) BB (20) HB (20) CG (20) PB (20): SOC (20) SWI (20) BB (20) HB (20) CG (20)	F	9.6 ± 1.0 9.2 ± 0.7 10.4 ± 0.5 9.9 ± 0.6 10.0 ± 0.5 12.3 ± 0.6 12.2 ± 0.6 13.1 ± 0.3 12.7 ± 0.9 12.1 ± 0.7	Cross-sectional	3.9 ± 1.8 4.9 ± 2.0 3.4 ± 1.5 3.4 ± 1.4 4.5 ± 1.7 4.1 ± 2.4 4.4 ± 1.4 3.9 ± 1.8	3.0 ± 0.0 3.8 ± 1.9 2.9 ± 0.4 3.1 ± 0.2 3.6 ± 0.8 4.4 ± 2.7 3.1 ± 0.2 4.2 ± 2.8
Plaza-Carmona et al. [30]	PPB (20): SOC (10) CG (10) PEPB (45): SOC (30) CG (15)	F	8.2 ± 0.1 9.7 ± 0.2	Cross-sectional	2.5 ± 0.7 4.3 ± 1.8	2

AT artificial turf, *BA* bone area, *BB* basketball, *BMC* bone mineral content, *BMD*
CG control group, *CSMI* cross-sectional moment of inertia, *DXA* dual-energy X-r
FHEAD femoral head, *FNECK* femoral neck, *FS* the shaft, *HB* handball, *HI* high/
INTROCH intertrochanteric region, *IT* intertrochanteric, *LAC* lacrosse, *LSP* lumb
narrow neck, *NN* narrow neck, *NS* not specify, *PAR* parquet, *PB* pubertal, *PPB* pr
repetitive/non-impact, *RSK* rope-skipping, *RUN* runners, *SJT* sprinters, jumpers,
soccer players, *SOF* softball, *SPA* single-photon absorptiometry, *SWI* swimmers,
volleyball, *WB* whole body, *WTRI* wards triangle, *Z* section modulus

Study	Participants			Study design	Training experience (y)	Weekly training (h)
	Number	Sex	Age			
			11.7 ± 0.1 10.9 ± 0.2			
Ubago-Guisado et al. [40]	PPB (60) SOC (11/9) (G/AT) BB (14/6) (SYN/PAR) HB (12/8) (SYN/SMO) PB (60) SOC (11/9) (G/AT) BB (7/13) (SYN/PAR) HB (8/12) (SYN/SMO)	F	10.0 ± 0.9 9.1 ± 0.9 10.3 ± 0.6 10.5 ± 0.3 9.7 ± 0.6 10.0 ± 0.7 12.6 ± 0.6 12.0 ± 0.6 13.3 ± 0.4 13.1 ±	Cross sectional	4.3 ± 1.4 3.3 ± 2.2 3.1 ± 1.5 4.0 ± 1.6 3.3 ± 1.4 3.5 ± 1.3 4.6 ± 1.4 4.3 ± 2.1 4.1 ± 2.0 4.5 ± 1.1 4.4 ± 2.2 3.6 ± 1.4	3.0 ± 0.0 3.0 ± 0.0 2.8 ± 0.5 3.0 ± 0.0 3.0 ± 0.0 3.1 ± 0.4 3.5 ± 0.8 3.7 ± 0.7 3.2 ± 0.3 3.0 ± 0.1 6.5 ± 3.4 6.0 ± 2.4

AT artificial turf, *BA* bone area, *BB* basketball, *BMC* bone mineral content, *BMD* *CG* control group, *CSMI* cross-sectional moment of inertia, *DXA* dual-energy X-r *FHEAD* femoral head, *FNECK* femoral neck, *FS* the shaft, *HB* handball, *HI* high/ *INTROCH* intertrochanteric region, *IT* intertrochanteric, *LAC* lacrosse, *LSP* lumb narrow neck, *NN* narrow neck, *NS* not specify, *PAR* parquet, *PB* pubertal, *PPB* pr repetitive/non-impact, *RSK* rope-skipping, *RUN* runners, *SJT* sprinters, jumpers, soccer players, *SOF* softball, *SPA* single-photon absorptiometry, *SWI* swimmers, volleyball, *WB* whole body, *WTRI* wards triangle, *Z* section modulus

Study	Participants			Study design	Training experience (y)	Weekly training (h)
	Number	Sex	Age			
			0.3 13.0 ± 1.0 12.5 ± 0.8			

AT artificial turf, *BA* bone area, *BB* basketball, *BMC* bone mineral content, *BMD*
CG control group, *CSMI* cross-sectional moment of inertia, *DXA* dual-energy X-r
FHEAD femoral head, *FNECK* femoral neck, *FS* the shaft, *HB* handball, *HI* high/
INTROCH intertrochanteric region, *IT* intertrochanteric, *LAC* lacrosse, *LSP* lumb
narrow neck, *NN* narrow neck, *NS* not specify, *PAR* parquet, *PB* pubertal, *PPB* pr
repetitive/non-impact, *RSK* rope-skipping, *RUN* runners, *SJT* sprinters, jumpers, a
soccer players, *SOF* softball, *SPA* single-photon absorptiometry, *SWI* swimmers,
volleyball, *WB* whole body, *WTRI* wards triangle, *Z* section modulus

Gender differences

The only study evaluating gender differences in bone mass between male and female adolescent soccer players was performed by McCulloch et al. [21], finding no differences in BMC or in BMD between genders but showing a tendency towards higher bone mass in female soccer players compared to their male counterparts. These results could be explained by the fact that females accumulate BMC earlier than males [18, 19].

Males

Comparison between soccer players and controls The first study that reported on bone mass in male children and adolescent soccer players and age-matched controls was performed by McCulloch et al. [21]. They observed that BMD tended to be increased in children and adolescent soccer players compared with controls, but these differences were not significant. Moreover, Vicente-Rodríguez et al. [44] showed that prepubertal soccer players had increased BMC at lower limbs and trochanter and increased BMD at pelvis, legs, lumbar spine, proximal femur, femoral neck, and trochanter compared with the control group. Nebigh et al. [24] showed similar results in pubertal but not in prepubertal soccer players compared to controls. In addition, Seabra et al. [34] also showed increased whole-body and lower limb BMD in soccer players compared to controls but not in the lumbar spine. Even considering other possible confounders, soccer participation by itself seems to be associated with increased bone mass. Considering this, Plaza-Carmona et al. [31] studied the influence of the playing surface (soft vs. hard ground). Independent of the playing surface, prepubertal soccer players showed increased BMC and BMD in most weight-bearing sites compared to controls, and no differences were found between playing surface groups. Although most of the studies use DXA, the quantitative ultrasound system (QUS) is another method to measure bone properties related to bone density and structure such as speed of sound (SOS), broadband ultrasound attenuation, and stiffness index. Madic et al. [17] used QUS reporting increased calcaneus SOS in soccer players compared to those of control subjects. In addition, a recent study performed by Vlachopoulos et al. [46] also reported that soccer players demonstrated an increased stiffness index, BMC, BMD, and bone structure at most weight-bearing sited compared to controls.

Today, few longitudinal studies have evaluated the effects of soccer practice on bone tissue during growth. Vicente-Rodriguez et al. [43], in a 3-year follow-up longitudinal study, reported greater increases in BMC and BMD parameters at the whole body, lower limbs, lumbar spine, femoral neck, and intertrochanteric region as well as a hypertrophic effect on bone in soccer players compared to controls. Three longitudinal studies performed by Zouch et al. [47, 48, 49] compared the bone tissue between two different activity groups. In the first study [47], although no differences were shown at baseline between soccer players and controls, positive increments for BMC at whole body, lumbar spine, total hip, and lower limbs were found in soccer players after 10 months of training, with higher increases in those who trained for 4 h per week compared with those who trained for 2 h per week. In the second study [48], participants were split into prepubertal and pubertal groups and were followed up for 1 year. Similarly, at baseline, prepubertal soccer players and controls demonstrated no BMC differences; however, pubertal soccer players showed increased BMC compared to controls. After a 1-year follow-up, greater increases for BMC at whole body, total hip, and lower limbs were observed for prepubertal soccer players compared to controls, whereas pubertal players also showed greater increases at lumbar spine. When both groups of soccer players were compared, greater BMC increases were reported in pubertal players than in prepubertal players. The last study performed by Zouch et al. [49] demonstrated increased BMD in whole body and both legs at baseline. After 3 years, soccer players presented increased BMC and BMD gains at whole body, lumbar spine, total hip, and lower limbs compared to the control group. In contrast, a study performed by Agostinete et al. [2] found no BMD accrual differences between young soccer players and controls after 9-month follow-up. It is important to state that the previous study had the lowest duration of follow-up and the hours per week of training in each sport were not reported.

The high-impact actions in the lower limbs caused by soccer practice could explain the positive influence of this sport on different weight-bearing sites such as pelvis, lower limbs, lumbar spine, and proximal femur. However, BMC and BMD differences at hip should be cautiously interpreted because the hip is a site with high variability during bone development [9]. Moreover, these differences between soccer players and controls are more marked in pubertal than prepubertal soccer players. On the other hand, the number of hours and days of training should be considered, as prepubertal soccer players perform fewer hours of training and have a shorter history of practice compared to pubertal ones.

Comparison with other athletes McCulloch et al. [21] compared soccer players with other athletes (including swimmers) and showed no differences in BMD at calcaneus. In addition, Falk et al. [10] found no SOS differences at tibia but increases at the radius in hockey players compared to soccer players. In contrast, Sanchis-Moysi et al. [33] found that adolescent soccer players had increased femoral neck BMD compared to tennis players, but these results were not corroborated by Silva et al. [35], although they showed increased values in these two groups compared with swimmers. Compared with previous studies, Vlachopoulos et al. [46] reported that soccer players had better bone structure, stiffness index, and BMD at most weight-bearing sites compared to swimmers and cyclists. However, arms, lumbar spine, and shaft bone area and arms BMD and BMC were increased in swimmers compared to soccer players. In addition, a longitudinal study performed by Agostinete et al. [2] showed that basketball players increased more whole body and arms BMD than soccer players.

These studies revealed that the differences in bone tissue at each bone site evaluated are highly influenced by the environment and the type of specific actions of each sport, as has been previously suggested [14]. Moreover, finding that there were no bone differences in lower limbs comparing soccer with hockey and tennis could be explained by the greater number of years of practice and training among hockey and tennis players compared with soccer players.

Comparison between soccer players Mota et al. [23] studied adolescent soccer players comparing them in three age groups and reported that soccer players who were under 17 years old showed increased BMD in the non-dominant leg when compared to the dominant leg, while those under 19 and under 15 presented this tendency without a significant difference. In the study by Ankiler et al. [3] increased bone mass and better bone geometry was shown in the non-dominant leg compared to the dominant leg evaluated with peripheral quantitative computed tomography (pQCT).

These differences between both legs could be explained by the fact that the non-dominant leg performs the majority of jumps and supports the action of the dominant leg while kicking. Thus, the loading suffered by the non-dominant leg is higher than that experienced by the dominant leg [34].

Hormone levels Discrepancies between studies in the effect of soccer on bone tissue during growth could be influenced by bone mineral accrual differences during growth [6] and the increases of important secreted hormones that influence bone mass during puberty [20]. Nevertheless, Nebigh et al. [24] reported increased IGF-1 and IGFBP-3 concentrations in prepubertal soccer players compared to age-matched controls, although these authors showed no differences in BMC and BMD between groups. However, hormonal concentrations, BMC and BMD variables studied in the pubertal soccer players were increased compared to those reported in controls. Therefore, these bone improvements derived from soccer training could be influenced by the levels of hormones such as IGF-1, IGFBP-3, GH, and testosterone. Moreover, soccer training during prepubertal stage could increase these hormones and consequently promote bone improvements.

In summary, bone properties are slightly improved in prepubertal soccer players compared to older soccer players, but at the same time, these improvements are greater in prepubertal soccer players compared to control subjects [48]. These bone differences between development stages could also be explained by the fact that pubertal soccer players have probably been exposed to soccer strains for more years than prepubertal soccer players. Therefore, prepuberty and puberty are important stages in the bone development process where playing some high-impact sport such as soccer could be beneficial to improving bone mass.

Each sport could have different effects on bone tissue depending on the biomechanics and the type of specific actions executed [10, 27]. Soccer players suffer more strains in their lower limbs, while other athletes such as hockey and tennis players have more strains in their upper limbs because actions are made with an implement such as a stick or a racket. These differences are minimized between high-impact sports; therefore, it is not clear if soccer practice provokes increased bone changes at weight-bearing sites compared to other high-impact sports.

Females

Comparison between soccer players and controls Soderman et al. [36] first evaluated bone characteristics between female soccer players and control subjects, finding increased BMD in every studied variable. Dividing the sample into two age-groups (younger or older than 16), younger players only showed differences at trochanter BMD, while the older players presented increased BMD at whole body and all weight-bearing sites compared to the control group. Ubago-Guisado et al. [41] reported increased femoral neck and trochanter BMC and intertrochanteric region BMD in prepubertal female soccer players compared to controls. They also showed increased BMC and BMD at most weight-bearing sites in pubertal soccer players compared to controls. Moreover, a recent study by Plaza-Carmona et al. [30], which compared bone mass and divided the groups by pubertal status, found similar results.

These results support that the osteogenic effect caused by high-impact actions from soccer is more evident in older athletes. Although younger athletes showed no significant differences compared with controls, a tendency existed towards increased BMC and BMD compared to controls, suggesting that soccer may have a positive influence on bone mass during growth. As suggested for males, the greater benefits found in older soccer players could be because older soccer players have been exposed to soccer loads for more years.

Comparison between soccer players and other athletes Petterson et al. [28] compared female soccer players with rope skippers, and no raw differences between athletes were observed, but when adjusting for lean body mass, soccer players showed decreased total body, lumbar spine, and right humerus BMD compared to rope skippers. In addition, soccer players also showed decreased tibia and radius BMC and femur and tibia bone area compared to rope skippers. The high impacts that rope skippers receive need to be considered.

Ferry et al. [11] compared female soccer players and swimmers and positive bone effects were only reported in soccer players, as also suggested by Plaza-Carmona et al. [29], who found increased BMC at total body, hip, and legs in female soccer players compared to swimmers. Bellew et al. [7] showed increased BMD in female soccer players compared to swimmers and weight lifters. In addition, they compared these results to normative data and found that those values in female adolescent soccer players were higher than those expected in adult controls. Ubago-Guisado et al. [41] compared female practicing soccer, swimming, handball, and basketball in prepubertal and pubertal stages. Prepubertal soccer players presented increased hip, femoral neck, and trochanter BMC and trochanter BMD compared to swimmers and higher BMC at femoral neck and trochanter than basketball players. Pubertal soccer players showed increased whole body, hip, femoral neck, trochanter and legs BMC, and pelvis and hip BMD compared to pubertal swimmers.

The study performed by Ferry et al. [12] was the only longitudinal study evaluating the effects of soccer practice on bone tissue in female soccer players. These authors reported that soccer practice improved bone characteristics after 1 year of practice, supporting the cross-sectional findings, whereas 1 year of swimming practice caused neither changes nor enhancements in bone mass.

The differences between athletes that practice high-impact sports such as soccer, basketball, or rope-skipping remain unclear. Although these sports are composed of high-impact movements, the loading patterns seem to be different, especially in relation to the direction of the forces, being that compressive forces are more common during jumps and that tensile forces are more common during versatile movements [28]. Therefore, team sports characterized by dynamic and versatile movements such as soccer seem to be the most adequate sports to provoke the best effect on bone [16]. However, the existence of some sports or physical exercises, such as rope-skipping (characterized by compressive forces and a continue high-impact loads), which could be more osteogenic than soccer, should be considered.

Comparison between soccer players Ubago-Guisado et al. [40] compared bone mass between soccer players who trained on the ground and those who trained on artificial turf. Moreover, the comparisons were stratified according to maturity status. They only reported higher hip BMC and BMD in pubertal soccer players who trained on the ground when compared to their counterparts who trained on artificial turf. However, no differences were found between prepubertal soccer groups. These results could be explained by the fact that prepubertal soccer players trained and played for fewer years and hours per week than their pubertal peers. On the other hand, because ground is harder than artificial turf, those soccer players who trained on the ground could have a higher osteogenic stimulus.

Menstrual cycle Nichols et al. [26] evaluated the interaction between menstrual status and the type of load caused by several sports in female soccer players. All bone comparisons performed in the study demonstrated that normal menstrual status and the practice of high-impact sports are the best interaction for obtaining high BMC and BMD.

BMC and BMD are influenced by the practice of high-impact sports such as soccer; nevertheless, menstrual status during adolescence highly influenced the bone mineralization and should therefore be considered [26]. It has also been described that menstrual irregularities could negatively affect bone independently of the practiced activity [26], causing loss of BMD and stress fractures in these athletes [37].

In summary, although there are few studies regarding young female soccer players, most of the studies included in this review reported increased bone mass values compared to other athletes and age-matched control subjects [7, 12, 25, 29, 36, 41], with only Petterson et al. [28], reporting decreased BMD compared with rope-skippers. Both sports are characterized by high ground reaction forces, but the direction of the forces is different: compressive forces are caused during jumping, which is the most repeated action while rope-skipping, and tensile forces are caused during the versatile movements that are typically found in soccer. Although soccer practice with a dynamic loading regimen characterized by unusual movements could cause a greater effect on bone mass [16], rope skippers in this study were more exposed to high-impact strains than soccer players. Moreover, sport-specific exercise during soccer training should be registered because this training could be developed at a low intensity, without including so many high-impact actions such as jumps, kicks, starts or stops.

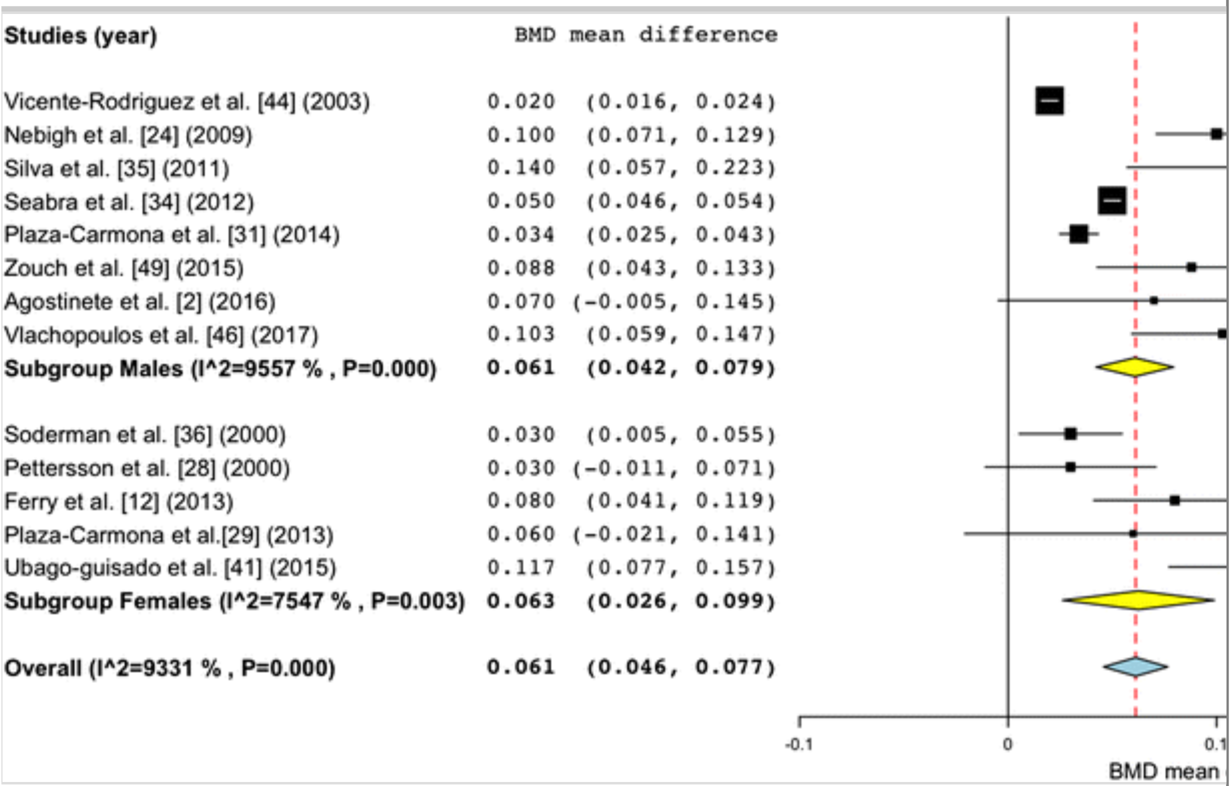
The effects of maturity stage on bone mass has been studied in young female soccer players, and the differences between soccer players and controls are more marked in pubertal than prepubertal soccer players. These results could be explained by the fact that bone development is more advanced in pubertal players than in prepubertal ones. Moreover, prepubertal soccer players have trained for fewer years than pubertal soccer player; therefore, the time of exposure is also lower, and this needs to be taken into account. In addition, those soccer players who had normal menstrual status and practiced high/odd-impact sports could be in the best condition to develop bone.

Meta-analysis results

A forest plot of whole-body BMD comparison between soccer players and controls separated by gender is shown in Fig. 2. Analyzing together the studies including male or female participants, BMD mean difference between soccer players and controls was 0.061 (95% CI, 0.046–0.077) associated with an extreme heterogeneity (I^2 = 93%). Analyzing males and females separately, BMD mean differences between soccer players and controls was 0.061 (95% CI, 0.042–0.079) in males and 0.063 (95% CI, 0.026–0.099) in females. Both gender analyses presented extreme heterogeneity (males: I^2 = 96%; females: I^2 = 75%).

Fig. 2

Forest plot of whole-body BMD mean difference between soccer players and controls. *BMD* bone mineral density, *CI* co nfidence interval 95% CI is missing in the seccond column label. Thus, Fig2. has been attached. , I^2 inconsistency index



The results of this meta-analysis reinforced the positive effects of soccer practice on bone mass during growth demonstrated along this systematic review. Furthermore, these analyses highlighted that positive effects are similar independently of the gender.

Limitations

Some limitations of this review should be recognized. Studies in languages other than English or Spanish were not included in this review; therefore, a language bias may be present. The age range of this systematic review is wide, from 8 to 18 years old. It is possible that, if a smaller age range was included, different results might have emerged due to the known differences in bone development between childhood and adolescence. Moreover, there were few studies of growing soccer players that evaluated bone strength using pQCT or hip structural analysis (HSA). Finally, descriptive variables that could modify bone mass values such as hours per week of soccer training, years of soccer practice, and calcium intake were not evaluated in several studies included in this review.

Conclusion

Overall, positive effects of soccer practice on bone mass at most weight-bearing sites during prepubertal and pubertal stages have been highly demonstrated. However, these effects are more marked in pubertal compared to prepubertal soccer players partially because pubertal athletes presented a bone development that was more advanced, had been playing soccer for more years, and have consequently been exposed to soccer loadings for more time. Lumbar spine, hip, femoral neck, trochanter, intertrochanteric region, and both legs are particularly sensitive to the mechanical loads elicited by soccer actions in either prepubertal and pubertal soccer players or male and female athletes. Moreover, the majority of osteoporotic fractures during adulthood occur in these weight-bearing sites, especially at lumbar spine and hip. Thus, soccer practice could be an adequate sport to reduce future osteoporotic problems in adults. Therefore, beginning to play soccer at the prepubertal stage and continuing during puberty seems to be appropriate for improving bone health during those developmental stages and in the future.

Perspective

Although positive effects of soccer practice on bone tissue in children and adolescents have been demonstrated, some questions remain unanswered.

The optimal type and amount of training for achieving the greatest bone improvements are still unknown as well as the adequate age or range of ages (if any) to begin playing soccer. Other parameters, such as the types of surface and shoes, should be taken into account because they could affect bone accretion. Moreover, the effects of soccer training on bone mass during a season or several seasons have been scarcely studied as well as the differences on BMC and BMD between prepubertal and pubertal soccer players. Therefore, future studies should take these considerations into account and attempt to answer them.

Authors' Contributions

All the authors have been actively involved in the planning and enactment of the study. JAC and GVR were the main researchers in the present study, and GLB was the first author. AML, AGA, AGB, and AGC were co-researchers. GLB and AML independently evaluated all studies, and AGA resolved inter-reviewer disagreements. GLB drafted the document, and AML, AGA, AGB, and AGC critically reviewed the document. All authors have read and approved of the manuscript.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants performed by any of the authors.

Electronic supplementary material

Supplementary Table 1 (DOCX 47 kb)

Supplementary Table 2 (DOCX 39 kb)

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