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Is Bone Tissue Really Affected by Swimming? A Systematic Review

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Abstract

Background: Swimming, a sport practiced in hypogravity, has sometimes been associated with decreased bone mass.

Aim: This systematic review aims to summarize and update present knowledge about the effects of swimming on bone mass, structure and metabolism in order to ascertain the effects of this sport on bone tissue.

Methods: A literature search was conducted up to April 2013. A total of 64 studies focusing on swimmers bone mass, structure and metabolism met the inclusion criteria and were included in the review.

Results: It has been generally observed that swimmers present lower bone mineral density than athletes who practise high impact sports and similar values when compared to sedentary controls. However, swimmers have a higher bone turnover than controls resulting in a different structure which in turn results in higher resistance to fracture indexes. Nevertheless, swimming may become highly beneficial regarding bone mass in later stages of life.

Conclusion: Swimming does not seem to negatively affect bone mass, although it may not be one of the best sports to be practised in order to increase this parameter, due to the hypogravity and lack of impact characteristic of this sport. Most of the studies included in this review showed similar bone mineral density values in swimmers and sedentary controls. However, swimmers present a higher bone turnover than sedentary controls that may result in a stronger structure and consequently in a stronger bone.

Introduction

Osteoporosis and related fractures are a considerable health concern worldwide [1] and cause increased morbidity, mortality and costs for society [2]. This disease is characterized by low bone density and microarchitectural deterioration of bone tissue with a consequent increase in bone fragility and susceptibility to fracture [3]. Adolescence is a critical period for bone acquisition [4], and epidemiological studies have suggested that achieving a high peak of bone mass during growth might decrease the risk of suffering osteoporosis and therefore osteoporotic fractures later in life [3,6]. In addition to genetic predisposition and physiological factors, calcium and vitamin D intake [4] and having an active lifestyle [7] are among the most important factors related to peak bone mass acquisition. Therefore, physical activity and participation in sport during growth periods are crucial for the acquisition of a high peak of bone mass and to prevent future related pathologies.

The osteogenic effect of exercise is mainly produced by the impacts and mechanical loads applied to the bone. The modelling and remodelling bone turnover process adapts the bone to new demands and, as a consequence, bone mineral content (BMC) and density (BMD) are modified [8,9]. It is possible that structural and trabecular microarchitecture adaptations are also produced [6]. However, not all physical activities have the same effects on bone; a minimum duration and intensity are required [10,11] in order for this osteogenic stimulus to be produced.

Recent literature reviews have shown that high impact sports seem to be more osteogenic than non impact sports such as swimming or cycling, in children [12], young adults [12] or older adults [13]. However, to date, systematic reviews compare sports, but none have focused specifically on swimming and bone, an area in which a vast amount of research has recently been produced. Nevertheless, results among studies remain disparate. Recent published studies that have not been included in any previous review show surprising results regarding bone structure in this population [14–17]. Therefore, a systematic review in this area is needed in order to elucidate the effect of swimming on bone.
Previous studies performed on swimmers use a variety of techniques to evaluate bone mass and bone metabolism. Dual-energy x-ray absorptiometry (DXA), as a ‘gold standard’ method for measuring bone mass, has been used to evaluate BMC and BMD. Peripheral quantitative computed tomography (pQCT) provides data regarding cortical and trabecular bone and, therefore, internal architecture, geometry and current bone strength. Another technique to evaluate bone parameters in swimmers has been quantitative ultrasound (QUS); its use in young populations is gaining rapid support because results are less likely to be affected by bone size and the technique is less expensive and invasive than other radiologic methods.

The heterogeneity of the studies (i.e. use of different devices, comparison groups, age range…) makes comparisons between studies difficult; however, a systematic review and summary of the available literature on bone mass and swimmers may help to detect possible concerns and to define topics for future research. Therefore the aim of this review was to summarize current knowledge on bone characteristics in swimmers.

Methods

Data sources and search strategy

This study followed the systematic review methodology proposed in the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement [18]. A PRISMA checklist is included (Table S1).

Studies were identified by searching within the electronic databases and consultation with experts in the field. This search was applied to PubMed, Embase and SportDiscus. The search was conducted up to and including 30 April 2013.

The thesaurus of the words: swimmer*, swimming (always the same descriptor for both terms), bone density, bone and bones were researched in each database. An advanced search was then carried out in which the thesaurus we had found (not always specific for each word) for the “bone terms” were combined with the Boolean operator “OR”. This resulted in a number which was subsequently combined with the number obtained from the “swimming/swimmer” thesaurus searched with the Boolean operator “AND”.

Two reviewers independently examined each database to obtain the potential publications. Relevant articles were obtained in full, and assessed against the inclusion and exclusion criteria described below. Inter-reviewer disagreements were resolved by consensus. Arbitration by a third reviewer was used for unresolved disagreements.

Inclusion criteria

1) Types of study: Cross-sectional, longitudinal, randomized and non-randomized controlled trials studying the effects of swimming training programmes on bone mass with or without coexistent treatments.
2) Types of participants: children, adolescents, adults and elderly populations.
3) Types of intervention: trials comparing the effects of following or not following an exercise training programme and descriptive cross-sectional or longitudinal studies.
4) Types of outcome measured: BMC and BMD of whole body, lumbar spine, arm, hip (femoral neck, trochanter, intertrochanter and Wards triangle subregions), bone architecture (from pQCT), ultrasound parameters (Broadband Ultrasound Attenuation (BUA), Speed of Sound (SOS), stiffness index) and metabolic biomarkers.

Exclusion criteria

1) Studies in languages other than English or Spanish 2) Unpublished data 3) Studies with animals 4) Studies without a control group that would permit comparison, and 5) Studies focusing exclusively on bone markers not measuring bone with an imaging technique.

Search summary

Searches identified 423 potentially relevant articles and an additional 7 articles were identified through reference lists. Following review of titles and abstracts and excluding the duplicates, the total was reduced to 154 potentially relevant papers for inclusion. Of these articles, 64 met the selection criteria and were included in this review (Figure 1).

Quality assessment

Studies were assessed using 2 different quality assessment tools. For cross-sectional studies we used the same quality assessment tool as Olmedillas et al. [19] that grades articles on a scale of 7 points. For longitudinal studies the checklist performed by Tooth et al. [20] was used, classifying articles on a scale composed of 33 items evaluating the study design and the internal validity.

Results and Discussion

Results have been divided into two sections; The first section (3.1) organized according to the type of device used for the bone analysis, and the second section (3.2) organized according to factors affecting bone mass. Studies included in this review are summarized in Tables 1–4.

Regarding the quality assessment; cross-sectional studies (Table S2) were mostly graded with a 4/7 (47 studies), fewer scored 5/7 (7 studies), and only 3 studies were graded with a 6/7. Longitudinal studies (Table S3) were poorly graded with a maximum of 15/33. This was in line with the results obtained by Tooth et al. [20] who designed the checklist and found a mean of 17/33 in the studies that they included in their review [20].

1. Bone assessment methods

1.1 BMD and BMC analyzed by photon absorptiometry. The majority of the studies included in this review used photon absorptiometry to assess bone mass in swimmers; in fact 53 of the 64 studies included used this method to evaluate bone mass (Table 1). Dual energy X-ray absorptiometry (DXA) is the most common photon absorptiometry method used. DXA is a two dimensional measure highly influenced by body size [21]. It therefore seems necessary to adjust by covariates to minimize the differences among participants when these are compared. The decision regarding which covariates better adjust the bone mass values is taken by each researcher, taking into account participant age-range, comparison group and so on. For the purposes of this review the final results and authors conclusions presented in each published work were used, regardless of the covariates employed and whether results had been adjusted.

Nilsson et al. [22] first evaluated bone mass in swimmers, other athletes and in a non-athletic control group (CG) aged 18 to 22. They observed higher BMD in the femur of all the athletes than in the CG; however, swimmers did not differ in BMD values when compared with the CG. These findings of similar BMD values in swimmers and CG were reinforced by subsequent studies that also compared swimmers bone mass with CG who performed less than 3 hours of physical activity per week in both male and female subjects, in children [23–27], adolescents [28–34] young adults [35–41] or elderly populations [35]. Some of these studies
included a comparison sport group that also showed no differences in BMD when compared with the swimmers [22,31,38,39]. Furthermore, some of the first studies performed on swimmers such as Jacobson et al. [42] or Orwoll et al. [43] as well as other studies found higher arm BMD [16,42–44] or BMC [45,46] in swimmers than in CG. However, other measured sites in these studies such as lumbar spine [16,42,45], a weight bearing zone, or whole body [44], were similar in swimmers and CG. These exclusive higher arm BMD values in swimmers may be due both to the level of force applied by the forearm muscles while swimming, and to the fact that this part of the body is not overly used in daily life by the general population. In fact, Orwoll et al. [43] who included both men and women in their study, found differences only in the male group. According to the authors this was due to the greater forces applied by males, not reached by females who presented values similar to their peer CG. Out of the 50 studies included in this review using DXA, only 2 [45,47] showed higher whole body BMD in swimmers than in CG. In both studies lean mass, which is well known to influence BMD, [48] was significantly higher in swimmers than in the CG, and was not included as a covariable in the comparisons. This fact may mask some important real differences. Nevertheless, neither of the two cross-sectional studies were graded with a 6/7 in the quality assessment.

Of the 6 studies [16,42–46] that showed higher upper limb BMD values in swimmers than CG, four were performed on adults over 40 years old suggesting that when practiced in the postmenopausal period swimming might reduce the rate of normal bone mass loss accompanying age [42,43]. However, those studies showing higher upper limb BMD in swimmers, all graded with a 4/7, and others performed with older aged populations [35], did not take into account other physical activities or sedentary behaviours during life, calcium intake [42,45] or lean mass [42,43,45], all of them variables affecting bone. In fact, when Dook et al. [44] controlled by lean mass, the differences in BMD between swimmers and CG disappeared. This may imply that swimming benefits muscle maintenance but the direct effect of swimming on bone mass at these ages is not clear.

Only 2 studies [37,45] took past physical activity into account: Andreoli et al. [45] performed a retrospective study concluding that physical activity during youth appeared to have a beneficial effect on bone mass later in life. This conclusion underlines the importance of registering past physical activity in studies evaluating bone mass in the elderly population. Greenway et al. [37] did in fact evaluate past, recent and current physical activity in addition to swim participation, and showed that swimmers, who presented fewer cases of lower bone mass than CG, had performed greater amounts of physical activity (excluding swimming) at the ages ranging from 10 to 19. These higher levels of physical activity registered in the study performed by Greenway et al. [37] may be similar physical activity patterns to those of older adult swimmers evaluated in other studies, who showed higher BMD values than CG but whose past physical activity was not registered.

The only longitudinal study performed in postmenopausal former swimmers showed lower BMD and BMC reductions during a one year follow-up in the former swimmers than the sedentary controls [49]. However, these former swimmers performed 3 times more current physical activity than the controls. Physical activity other than swimming may be the cause of higher BMD and should therefore be taken into account in further studies focused on evaluating bone in a later adulthood population.
| Study | Participants | Study design | Training years | Training hours/week | Data source | Measured areas | Outcome |
|-------|--------------|--------------|----------------|---------------------|-------------|----------------|---------|
| Nilsson et al. [22] 1971 | 1971 SWI (9) M 17.9 ± 4.5 | Case-control | – | 20.7 ± 8.4 | Photon-absorption Femur method | Femur | All athletes had significantly higher femoral BMD compared to CG except SWI that did not significantly differ. |
| | SOC (15) F 22.5 ± 5.1 | Case-control | ≥3 | ≥3 | DXA | Femur LSP | Females showed no differences in BMD among groups. No differences in calcium intake among groups. |
| | SVN (25) F 24.9 ± 5.2 | Case-control | ≥3 | ≥3 | DXA | Femur | Females showed no differences in BMD among groups. No differences in calcium intake among groups. |
| | RUN (23) F 25.5 ± 5.1 | Case-control | ≥3 | ≥3 | DXA | Femur | Females showed no differences in BMD among groups. No differences in calcium intake among groups. |
| | CG (119) 60 ± 12 | Case-control | – | 3 times per week | DXA | Femur LSP | Females showed no differences in BMD among groups. No differences in calcium intake among groups. |
| | TEN (11) 21.7 ± 3.0 | Case-control | 10.5 | 10 | DXA | Femur LSP | Females showed no differences in BMD among groups. No differences in calcium intake among groups. |
| | CRU (9) 20.2 ± 1.1 | Case-control | 10.5 | 10 | DXA | Femur LSP | Females showed no differences in BMD among groups. No differences in calcium intake among groups. |
| Jacobson et al. [42] 1984 | SWI (23) F 23–75 | Case-control | – | 3 times per week | DXA | Lumbar spine | Male SWI had higher BMD at radial and vertebral measured sites than CG. No differences in calcium intake among groups. |
| | TEN (11) 23–75 | SPA | Metatar. Radius | 23–75 | SPA | Metatar. Radius | Male SWI had higher BMD at radial and vertebral measured sites than CG. No differences in calcium intake among groups. |
| | TEN (86) 23–75 | CG (23–75) | Metatar. Radius | 23–75 | SPA | Metatar. Radius | Male SWI had higher BMD at radial and vertebral measured sites than CG. No differences in calcium intake among groups. |
| | WHI (99) M 60 ± 13 | Case-control | – | 23 | DXA | Femur LSP | Male SWI had higher BMD at radial and vertebral measured sites than CG. No differences in calcium intake among groups. |
| | CG (119) 60 ± 12 | Case-control | – | 3 times per week | DXA | Femur LSP | Male SWI had higher BMD at radial and vertebral measured sites than CG. No differences in calcium intake among groups. |
| | SOC (15) 20.2 ± 1.1 | Case-control | 10.5 | 10 | DXA | Femur LSP | Male SWI had higher BMD at radial and vertebral measured sites than CG. No differences in calcium intake among groups. |
| | CG (119) 60 ± 12 | Case-control | – | 3 times per week | DXA | Femur LSP | Male SWI had higher BMD at radial and vertebral measured sites than CG. No differences in calcium intake among groups. |
| | SOC (15) 20.2 ± 1.1 | Case-control | 10.5 | 10 | DXA | Femur LSP | Male SWI had higher BMD at radial and vertebral measured sites than CG. No differences in calcium intake among groups. |
| | SOC (15) 20.2 ± 1.1 | Case-control | 10.5 | 10 | DXA | Femur LSP | Male SWI had higher BMD at radial and vertebral measured sites than CG. No differences in calcium intake among groups. |
| | SOC (15) 20.2 ± 1.1 | Case-control | 10.5 | 10 | DXA | Femur LSP | Male SWI had higher BMD at radial and vertebral measured sites than CG. No differences in calcium intake among groups. |
| | SOC (15) 20.2 ± 1.1 | Case-control | 10.5 | 10 | DXA | Femur LSP | Male SWI had higher BMD at radial and vertebral measured sites than CG. No differences in calcium intake among groups. |
Table 1. Cont.

| Study | Participants | Study design | Training years | Training hours/week | Data source | Measured areas | Outcome |
|-------|--------------|--------------|----------------|---------------------|-------------|----------------|---------|
| SOC (23) | F 15.3±0.77 | 10 | Measured areas | No differences in calcaneum density between SWI and CG |
| CG(25) | F 14.9±0.56 | Calcium intake | BMC between SWI and SOC |
| Xia Qu MA [80] 1992 | SWI (6) M 18 X-ray Humeri | SWI humeri diameter was lower than DIS |
| GYM (8) | Calcium intake | SW showed lower cortex humeri than WLI |
| JAB (7) | Calcium intake | No differences between SWI and CG |
| DIS (9) | Calcium intake | |
| WLI (11) | Calcium intake | |
| CG (5) | Calcium intake | |
| Grimston et al. [55] 1993 | SWI (17) M-F 12.6±0.4 | SWI had lower BMD at femoral neck |
| WBE (17) | Calcium intake | Male swimmers had lower lumbar spine BMD than WBE |
| Taaffe et al. [61] 1995 | SWI (26) F 19.2±2.1 | SW showed lower whole body BMAD than GYM |
| GYM (19) | Calcium intake | SW showed lower femoral neck BMAD than GYM and CG |
| CG (19) | Calcium intake | No differences in calcium intake among groups |
| Lee et al. [58] 1995 | SWI (7) F 18.9±1.5 | SW showed lower BMD between SWI and CG. |
| VOL (11) | Calcium intake | SW showed lower BMD than BAS and VOL |
| BAS (7) | Calcium intake | SW showed lower Wards triangle BMD than BAS |
| SOC (9) | Calcium intake | SW showed lower femoral neck BMD than SOC |
| MOD (17) | Calcium intake | No differences in calcium intake among groups |
| SED (11) | Calcium intake | |
| Fehling et al. [36] 1995 | SWI (7) F 20.1±0.8 | No differences in BMD between SWI and CG. |
| VOL (11) | Calcium intake | |
| BAS (7) | Calcium intake | |
| SOC (9) | Calcium intake | |
| MOD (17) | Calcium intake | |
| SED (11) | Calcium intake | |
| Swimming and Bone Tissue | | | | | | | |
| Study                | Participants | Study design | Training years | Training hours/week | Data source | Measured areas | Outcome                                                                 |
|---------------------|--------------|--------------|----------------|---------------------|-------------|----------------|--------------------------------------------------------------------------|
| VOL (8)             |              |              | 8.0 ± 2.8       | 20                  |             |                | SWI showed lower BMD at lumbar spine, femoral neck, wards triangle, legs, pelvis and whole body than VOL and GYM |
| GYM (13)            |              |              | 9.8 ± 3.0       | 20                  |             |                | SWI showed lower arm BMD than GYM                                      |
| CG (17)             |              |              | 20.8 ± 1.2      | <1                  |             |                |                                                                          |
| Cassell et al. [23] | SYS (5)      | F            | 9.0 ± 0.2       | 4.7                 | DXA         | WB             | No differences in BMD between SWI and CG                                 |
| SSW (9)             |              |              | 9.0 ± 0.2       | 4.7                 |             |                | SWI showed lower whole body BMD than GYM                                 |
| GYM (14)            |              |              | 8.8 ± 0.2       | 13.9                | Calcium intake |                | No differences in calcium intake among groups                             |
| CG (17)             |              |              | 8.3 ± 0.2       |                     |             |                |                                                                          |
| Dook et al. [44]    | SWI (20)     | F            | 42–50           | ≥20                 | DXA         | WB             | SWI showed lower whole body and regional leg BMD than HIG               |
| HIG (20)            |              |              |                |                     |             |                | SWI showed higher regional arm BMD than CG                               |
| MED (20)            |              |              |                |                     | Calcium intake |                | No difference in calcium intake among groups                             |
| CG (20)             |              |              |                |                     |             |                |                                                                          |
| Matsumoto et al. [94] | SWI (28)   | M-F          | 19.2 ± 0.7 F 19.6 ± 1.0 | ≥4                  | DXA         | WB             | SWI showed lower BMD than JUD                                          |
| LDR (38)            | M            |              | 19.5 ± 0.4 F 19.4 ± 0.4 |                     |             |                | No differences in BMD between SWI and LDR                               |
| JUD (30)            | M            |              | 19.8 ± 0.6 F 19.4 ± 0.7 |                     | Bone markers |                | Male SWI showed higher B-ALP values than male LDR                        |
| Taffe et al. [60]   | SWI (11)     | F            | 19.0 ± 1.2      | 12 month follow-up | DXA         | FNECK LSP WB | SWI showed lower deoxypyridinoline levels than JUD                       |
| GYM (8)             |              |              | 18.9 ± 1.1      | Start training (years)7.0 ± 3.5 |             |                | SWI femoral neck and whole body BMD was lower than GYM                  |
| CG (11)             |              |              | 20.0 ± 2.0      | Start training (years)7.0 ± 3.5 |             |                | SWI gained less bone than GYM during the 12 month period                |
|                     |              |              |                |                     |             |                | No differences in gained BMD between SWI and CG                          |
| Study | Participants | Study design | Training years | Training hours/week | Data source | Measured areas | Outcome |
|-------|--------------|--------------|----------------|---------------------|-------------|----------------|---------|
| Emslader et al. [105] 1998 | SWI (22) | F | 20.5±0.32 | Case-control | ≥3 | 10 miles per week | DXA | FNECK LSP WB | No differences in BMD among groups. |
|          | RUN (21) | 20.3±0.36 | ≥3 | 40 miles per week | No differences regarding calcium intake among SWI and RUN |
|          | CG (20) | 20.4±0.32 | Calcium intake | SWI had higher calcium intake than CG |
| Courteix et al. [26] 1998 | SWI (10) | F | 10.5±1.4 | Case-control | ≥3 | – | DXA | FNECK Hip LSP Radius TROCH | No differences in BMD between SWI and CG |
|          | GYM (18) | 10.4±1.3 | SWI showed lower BMD at lumbar spine, femoral neck, wards triangle and overall radius when compared to GYM |
|          | CG (13) | 10.7±1 | |
| Courteix et al. [25] 1998 | SWI (10) | F | 10.5±1.4 | Case-control | ≥3 | 8–12 | DXA | FNECK Hip LSP Radius TROCH | |
|          | GYM (18) | 10.4±1.3 | 10–15 | |
|          | CG (13) | 10.7±1 | 2 | Calcium intake | |
|          | |
| Taaffe et al. [65] 1999 | SWI (11) | M | 19.9±1.2 | Case-control | Start training [years] 10.7±3.7 | 24.7±4.2 | DXA | Femur LSP WB | No differences in BMD among groups |
|          | CG (11) | 19.1±1.6 | 3.4±1.6 | |
| Courteix et al. [24] 1999 | SWI (12) | F | 10.6±1.1 | Case-control | ≥3 | 8–12 | DXA | FNECK Head LSP Radius TROCH WTRI | |
|          | GYM (32) | 10.15±1.4 | ≥3 | 10–15 | |
|          | CG (16) | 10.5±1.1 | 2 | Calcium intake | |
|          | |
| Kearny [38] 2000 | SWI (8) | F | 11.0±1.07 | Case-control | ≥6 months | 5–8 | DXA | FNECK LSP TROCH WB WTRI | No differences in BMD between SWI and GYM in whole body, hip and lumbar spine. |
|          | GYM (8) | 11.75±0.89 | 15–24 | |
| Creighton et al. [57] 2001 | SWI (7) | F | 18–26 | Case-control | ≥4 | 10–13 | DXA | FNECK LSP TROCH WB WTRI | No differences in BMD between SWI and CG |
| Study           | Participants | Study design | Training years | Training hours/week | Data source | Measured areas | Outcome                                                                 |
|-----------------|--------------|--------------|----------------|--------------------|-------------|----------------|--------------------------------------------------------------------------|
| Taffe et al. [41] 2001 | SWI (10)     | M            | 25.5±5.6       | 12                 | SPA         | CalcaneusLeg     | SWI had lower values than JUM for BMC and BMD                           |
|                 | JUM (10)     |              | 24.9±3.9       |                    |             |                | No differences in BMC and BMD for SWI and CG                             |
|                 | CG (10)      |              | 27.7±7.3       |                    |             |                |                                                                          |
| Lima et al. [47] 2001 | ALG (27)     | M            | 14.9±1.6       | 4.8±3.1            | DXA         | FNECK LSP WB      | SWI showed higher total BMC and BMD than the CG                          |
|                 | ILG (18)     |              | 15.6±1.7       | 5.7±2.7            |             |                | SWI showed lower lumbar spine and total BMC than the impact group       |
|                 | CG (24)      |              | 15.2±2.0       | 2–3                | Bone markers |                | SWI showed higher B-ALP levels than the impact group                    |
|                 |              |              |                | Calcium intake     |             |                | SWI showed higher Dpd levels than the CG                                |
|                 |              |              |                | No differences in calcium intake among groups             |             |                |                                                                          |
| Morel et al. [52] 2001 | SWI(34)      | M            | 22±3.6         | 8.7±4.8            | DXA         | Arms Head Legs LSP WB | SWI showed lower total BMD than all the other groups except for ROW     |
|                 | RUN(26)      |              | 34±8.5         | 8.1±5.3            |             |                | SWI showed lower arm BMD than Fig and RUG                              |
|                 | RUG(110)     |              | 26±5.9         | 8.7±5.6            |             |                | SWI showed lower leg BMD than RUG, Fig, TEAM                             |
|                 | TRI(91)      |              | 30±8.1         | 8.3±4.6            |             |                |                                                                          |
|                 | MMA(65)      |              | 33±8.1         | 4±5.2              |             |                |                                                                          |
|                 | SOC(47)      |              | 29±7.3         | 6.7±4.8            |             |                |                                                                          |
| Study          | Participants | Study design | Training years | Training hours/week | Data source | Measured areas | Outcome                                      |
|---------------|--------------|--------------|----------------|---------------------|-------------|----------------|----------------------------------------------|
| Duncan et al. [30] 2002 | SWI (15) F | 16.7±1.3 Case-control | 6.1 | 15±4.8 DXA | Arms FNECK Leg LSP WB | No differences in BMD between SWI and CG |
|               | CYC (15) | 16.5±1.4 | 3.1 | 15±49 | DXA | SWI showed lower BMD at femoral neck, leg and total body than RUN |
|               | RUN (15) | 17.6±1.4 | 5.0 | 8.4±1.2 | MRI | SWI showed lower leg BMD than TRI |
|               | TRI (15) | 17.7±1.1 | 2.5 | 16.2±4.7 | | |
|               | CG (15) | 16.9±0.9 | <2 | | | |
| Duncan et al. [31] 2002 | SWI (10) F | 16.7±1.3 Case-control | 6.1 | 15±4.8 DXA | WB | No differences in vBMD, BMC or bone volumes among groups |
|               | CYC (10) | 16.5±1.4 | 3.1 | 15±49 | MRI | SWI had a smaller size-adjusted BSI and CSMI than RUN |
|               | RUN (10) | 17.6±1.4 | 5.0 | 8.4±1.2 | | No differences in BSI among SWI, CYC, TRI and CG |
|               | TRI (10) | 17.7±1.1 | 2.5 | 16.2±4.7 | | SWI had higher size-adjusted medullary cavity CSA and lower cortical CSA compared with RUN and TRI |
|               | CG (10) | 16.9±0.9 | <2 | | Calcium intake | No differences in calcium intake among groups |
| Maimoun et al. [39] 2003 | SWI (13) M | 25.4±6.5 Case-control | 12.6±5.6 | 10.7±3.2 DXA | Femur FNECK LSP Radius TROCH | SWI showed no differences in BMD when compared with the other groups |
|               | CYC (11) | 27.4±5.8 | 9.3±6.8 | 10.6±3.9 | | SWI showed higher Testosterone levels than CYC |
|               | TRI (14) | 25.7±6.6 | 9.3±6.8 | 15.2±4.3 | Bone markers | No differences in luteinizing hormone, estrogen, free androgen index, sex hormone-binding globulin, and cortisol among athletes |
|               | CG (10) | 27.5±4.3 | <2 | Calcium intake | | SWI had higher calcium intake than CG |
| Study                  | Participants | Study design | Training years | Training hours/week | Data source | Measured areas | Outcome                                                                 |
|-----------------------|--------------|-------------|----------------|---------------------|-------------|----------------|-------------------------------------------------------------------------|
| Maımoun et al. [40] 2004 | SWI (13)     | M 25.4±6.5 | Case-control   | 12.6±5.6            | DXA         | Femur FNECK LSP Radius WB | SWI showed no differences in BMD when compared with the other groups |
|                       | CYC (11)     | 27.4±5.8   |                | 9.3±6.8             | Bone markers|                | OC and CTX concentrations were higher in swimmers than CG              |
|                       | TRI (14)     | 25.7±6.6   |                | 6.2±2.2             | B-ALP       |                | B-ALP concentrations were not different among SWI, TRI and CG being higher in these than in CYC |
|                       | CG (10)      | 27.5±4.3   |                | <2                  | Serum calcium, phosphate, iPTH and 1,25(OH) vitamin D were similar in the four groups |
| Bellew et al. [68] 2006 | SWI (29)     | F 12.0±2.1 | Case-control   | 5.2±2.5             | SPA         | Calcaneus       | SWI showed lower BMD than SOC                                           |
|                       | SOC (16)     | 15.1±1.2   |                | 4.9±1.8             |              |                | No differences in BMD between SWI and WLI                               |
|                       | WLI (19)     | 13.6±1.3   |                | 5.1±2.4             |              |                | SWI showed lower BMD than reference values                             |
| Magkos et al. [51] 2007 | SSW (9)      | M 21.0±2.2 | Case-control   | –                   | DXA         | WB              | SWI showed lower aBMD at the legs than RUN                               |
|                       | ESW (7)      | 19.4±1.9   |                | –                   |              |                | SWI showed lower leg and total body aBMD than the other groups          |
|                       | SRU (11)     | 23.4±3.1   |                | –                   |              |                | The intensity of exercise had significant main effects on aBMD at nearly all regions examined |
|                       | ERU (10)     | 23.4±3.8   |                | –                   |              |                |                                                                         |
|                       | CG (15)      | 22.0±3.3   |                | –                   |              |                |                                                                         |
| Magkos et al. [46] 2007 | SWI (26)     | M-F 20.3±0.6 F 19.8±0.8 | Case-control | –                   | DXA         | WB              | SWI showed lower leg and total BMD than CG                               |
|                       | WPO (43)     | M 24.6±0.8 F 22.0±0.7 |                | –                   |              |                | Female SWI had higher arm BMC than CG                                   |
|                       | CG (30)      | M 22.0±0.9 F 22.9±0.6 |                | –                   |              |                | Male SWI showed lower leg BMC than CG                                   |
| Mudd et al. [53] 2007 | SWI (9)      | F 20.4±1.1 | Case-control   | –                   | DXA         | Leg LSP Pelvis WB | SWI showed lower average leg BMD scores than all other athletes except for RUN and CRW |
|                       | GYM (8)      | 19.7±0.9   |                | –                   |              |                | SWI showed lower whole body BMD than TRA, SOF, GYM and FHO              |
|                       | SOF (14)     | 20.1±1.1   |                | –                   |              |                |                                                                         |
| Study | Participants | Study design | Training years | Training hours/week | Data source | Measured areas | Outcome |
|-------|--------------|--------------|----------------|---------------------|-------------|----------------|---------|
|       | Number       | Sex          | Age            |                     |             |                |         |
| RUN (25) | 20.4±1.3 |              |                |                     |             |                |         |
| TRA (8)  | 20.1±1.3 |              |                |                     |             |                |         |
| FHO (10) | 19.8±1.2 |              |                |                     |             |                |         |
| SOC (10) | 19.8±0.9 |              |                |                     |             |                |         |
| CRW (15) | 20.5±2.1 |              |                |                     |             |                |         |
| Nichols et al. [114] 2007 | SWI & REP (68) | F 15.6±1.3 | Case-control | – | – | DXA | FNECK Hip LSP TROCH WB | SWI & REP eumenorrheic athletes showed lower total hip and trochanter BMD than HIL eumenorrheic athletes |
| HIL (93) | 15.6±1.2 |              |                |                     |             |                |         |
| Derman et al. [28] 2008 | SWI (40) | M-F | M 10–17 F 9–16 | Case-control | >3 | 2 h/day | DXA | WB | Male SWI had higher BMD Z-scores than CG |
| CG (40) | M 10–16 F 10–16 | | | | | | Bone markers | No differences in BMD between male or female SWI and CG |
| Velez et al. [35] 2008 | SWI (43) | M-F | ≥65 | Case-control | – | – | DXA | FNECK Hip LSP Radius WB | No differences in BMD among SWI and CG |
| RUN (44) | | | | | | | SWI showed lower hip intertrochanter BMD than RUN |
| CG (87) | | | | | | | Calcium intake | Swimmers showed lower calcium intake than runners and higher than the CG |
| Jürimaë et al. [27] 2009 | SWI (28) | M | 10–16 | Case-control | ≥2 | 8.4±1.7 | DXA | LSP WB | BMD increased through puberty with no differences among groups |
| CG (28) | | | | | | | Bone markers | In SWI Ghrelin was the most important hormonal determinant for total BMD and lumbar BMD |
| Carbuhn et al. [50] 2010 | SWI (16) | F | 17–21 | 1 year follow-up | – | – | DXA | Arm Leg LSP Pelvis | SWI showed lower BMD than all other athletes at preseason and postseason |
| SOF (17) | | | | | | | SWI increased arm, leg, pelvis, spine and total BMD from the preseason to the postseason period |
Table 1. Cont.

| Study | Participants | Sex | Age | Study design | Training years | Data source | Measured areas | Outcome |
|-------|--------------|-----|-----|--------------|----------------|-------------|----------------|---------|
| BAS (10) | 18–21 | | | | | | | SWI increased total BMC from the preseason to the postseason period |
| VOL (7) | 19–20 | | | | | | | |
| TRA, JUM & SRU (17) | 17–23 | | | | | | | |
| Gruodytė et al. [56] 2010 | SWI (24) | F | 13.7±1.2 | Case-control | ≥2 | 9.4±3.2 | DXA | FNECK LSP | SWI showed lower femoral neck BMC than RYG |
| | SPG (49) | | 14.0±0.9 | | | | | 4.8±1.3 | |
| | TSR (24) | | 14.3±1.1 | | | | | 4.8±2.2 | Bone markers |
| | RYG (23) | | 14.3±1.0 | | | | | 9.6±4.9 | |
| | CCS (17) | | 13.9±0.9 | | | | | 6.3±1.1 | |
| | CG (33) | | 14.2±1.1 | | | | | 90 min. of physical education | |
| Morgan et al. [59] 2011 | SWI (11) | F | 20.1±1.7 | 4–6 Month follow-up | – | 10–17 | DXA | FNECK Hip LSP TROCH WTRI | No differences in BMD between SWI and CG |
| | BAS (6) | | 19.7±0.8 | | | | | 10–13 | |
| | SOC (12) | | 19.2±1.3 | | | | | 8–13 | |
| | CG (4) | | 19.3±1.9 | | | | | <1 | |
| | SWI showed lower total hip BMC than BAS and SOC |
| | SWI showed lower BMC for femoral neck, trochanter and total hip than BAS |
| | SWI showed lower BMC for femoral neck and total hip than SOC |
| | No differences regarding BMD over time compared with all the other groups |
| | Bone markers |
| | SWI showed lower B-ALP levels than BAS and SOC |
| | No differences were found in bone resorption markers (NTx) among groups |
| Study                  | Study participants | Study design   | Training years | Training hours/week | Data source | Measured areas | Outcome                                                                 |
|-----------------------|--------------------|----------------|----------------|--------------------|-------------|----------------|-------------------------------------------------------------------------|
| Dias Quiterio et al. [29] 2011 SWI (20) | M 16.4±2.5         | Case-control   | Starting age 8.7±2.8 | 1.1±6.2            | DXA         | Limbs LSP WB     | No differences in calcium intake among groups                            |
|                        |                    |                |                |                    |             |                | No differences in BMD between SW and CG                                 |
|                        |                    |                |                |                    |             |                | SWI showed lower leg BMD, BMC and BA than HIG                             |
|                        |                    |                |                |                    |             |                | SWI showed lower lumbar spine BMC than HIG                               |
|                        |                    |                |                |                    |             |                |                                                                         |
| Silva et al. [33] 2011 SWI (12) | M 13.8±2.5         | Case-control   | ≥3             | 17.3±1.6           | DXA         | Femur LSP WB       | SWI showed lower proximal femur BMD than SOC and TEN                     |
|                        |                    |                |                |                    |             |                |                                                                         |
|                        |                    |                |                |                    |             |                | SWI showed lower values in parameters reflecting bone strength (CSMI, Z, BR) than SOC  |
|                        |                    |                |                |                    |             |                | SWI had HSA Z-scores below the normal values of CG                      |
|                        |                    |                |                |                    |             |                |                                                                         |
| Długolecka et al. [34] 2011 SWI (41) | F 11.5±1.0         | Case-control   | 2.4±1.2        | 12.0±3.2           | DXA         | LSP             | No differences in BMD between SW and CG                                 |
|                        |                    |                |                |                    |             |                |                                                                         |
|                        |                    |                |                |                    |             |                | SWI had higher calcium intake than CG although both groups on average did not exceed 49% of normal sufficient consumption  |
|                        |                    |                |                |                    |             |                |                                                                         |
| Ferry et al. [14] 2011 SWI (26) | F 15.9±2         | Case-control   | ≥6             | 10                 | DXA         | FNECK Hip LSP WB | SWI showed lower BMC and BMD than SOC                                   |
|                        |                    |                |                |                    |             |                |                                                                         |
|                        |                    |                |                |                    |             |                | SWI showed lower values in parameters reflecting bone strength (CSMI, Z, BR) than SOC  |
|                        |                    |                |                |                    |             |                | SWI had HSA Z-scores below the normal values of CG                      |
|                        |                    |                |                |                    |             |                |                                                                         |
| Greenway et al. [37] 2012 SWI (43) | F 40.4±7.9        | Retrospective  | >5             | ≥2                 | DXA         | FNECK LSP Radius Tibia WB | No differences in BMD or BMC among groups                              |
|                        |                    |                |                |                    |             |                |                                                                         |
|                        |                    |                |                |                    |             |                | SWI had higher calcium intake than SOC                                  |
|                        |                    |                |                |                    |             |                |                                                                         |
| Andreoli et al. [45] 2012 SWI (12) | F 58.4±8.8        | Retrospective  | >20            | 5.1±2.1            | DXA         | LSP WB           | SWI and RUN showed higher BMD values than GC in most of the measured zones |
|                        |                    |                |                |                    |             |                |                                                                         |
|                        |                    |                |                |                    |             |                | SWI showed lower leg BMC than RUN                                       |
| Study                | Participants | Sex | Age   | Study design       | Training years | Training hours/week | Data source | Measured areas | Outcome                                                                 |
|---------------------|--------------|-----|-------|--------------------|----------------|---------------------|-------------|----------------|--------------------------------------------------------------------------|
| Ferry et al. [15]   | SWI (26)     | F   | 15.9±2| 8 month follow-up | ≥6             | 10                  | DXA         | FNECK Hip LSP WB | SWI showed lower BMD than SOC at baseline and less changes during the longitudinal period |
|                     |              |     |       |                    |                |                     |             |                | SWI decreased their BMD Z-score for whole body and lumbar spine          |
|                     | SOC (32)     |     | 16.2±0.7| ≥7               |                | 10                  |             | HSA            | SWI did not increase sub-periosteal width while SOC did.                 |
|                     |              |     |       |                    |                |                     |             |                | SWI increased femoral shaft CSA but this increase was higher in SOC       |
|                     |              |     |       |                    |                |                     |             |                | SWI showed no changes in CSMI and Z Z-scores at femoral shaft section while SOC improved these parameters |
|                     |              |     |       |                    |                |                     |             |                | SWI showed lower aBMD than RYG at the femoral region except for skull     |
|                     |              |     |       |                    |                |                     |             |                | SWI improved Z-score of BR while SOC did not                             |
|                     |              |     |       |                    |                |                     |             | Calcium intake   | SWI had higher calcium intake than SOC                                  |
| Czeczuk et al. [49]| SWI1 (11)    | F   | 52.1±3.3| 12 month follow-up| Currently not swimming | Current PA 4.8   | DXA         | LSP            | SWI1 and CG1 showed higher BMC and BMD than SWI2 and CG2               |
|                     | SWI2 (7)     |     | 63.3±4.3|                   |                | Current PA 6.3     |             |                | SWI1 BMC and BMD decreased less after a year than CG1                    |
|                     | CG1 (11)     |     | 50.7±2.2|                   | Current PA 1.4  | Calcium intake     |             |                | SWI1 and SWI2 had higher calcium intake than CG1 and CG2                |
|                     | CG2 (7)      |     | 60.6±2.3|                   | Current PA 0.6  |                     |             |                |                                                                           |
| Hind et al. [67]   | SWI (10)     | M   | 23.2±4.3| Case-control      | >3             | >5                  | DXA         | Femur          | No difference in BMD between SWI and the rest of the groups.            |
|                     | RUN (31)     |     | 27.2±4.4|                   | >3             | >5                  | HSA         |                | SWI showed shorter Hip axis length than RUN and CG                       |
|                     | GYM (14)     |     | 22.5±2.0|                   | >3             | >5                  |             |                | SWI showed lower CSMI than runners                                      |
|                     | CG (22)      |     | 26.4±5.4|                   |                |                     |             |                | SWI showed lower Femoral Strength Index than runners                    |
| Maimoun et al. [17]| SWI (20)     | F   | 14.1±1.8| Case-control      | Starting age 6.5±1.814±5920.3±4.221.1±4.42.5±0.5 | DXA         | FNECK LSP Pelvis Radius Skull TROCH WB | SWI showed lower aBMD than ARG at all the measured sites except for skull |
|                     | ARG (20)     |     | 13.8±2.0|                   | Starting age 5.6±1.7 |                |             |                | SWI showed lower aBMD than RYG at the femoral region                    |
|                     | RYG (20)     |     | 13.8±2.2|                   | Starting age 6.6±1.2 |                | HSA         |                | SWI showed lower CSA and mean cortical thickness and higher buckling ratio than ARG and RYG |

*Note: GA (22) 27.2 ± 5.4: Smoking and Bone Tissue.*
| Study                                | Participants | Study design | Training years | Training hours/week | Data source | Measured areas | Outcome                                                                 |
|-------------------------------------|--------------|--------------|----------------|--------------------|-------------|----------------|----------------------------------------------------------------------|
|                                     |              |              |                |                    |             |                |                                                                      |
|                                      | Number | Sex | Age          |                   |             |                |                                                                      |
| Maimoun et al. [16] 2013            | SWI (25) | F   | 12–18.1      | 12 month follow-up| >5 years    | DXA            | SWI showed higher arm BMD than CG                                    |
|                                     | CG (21)    |     | 1.8 ± 1.2    |                    |             |                | No differences were found in BMD variation after a year between groups|
|                                      | HSA        |     |              |                    |             |                |                                                                      |
| Czeczelewski et al. [66] 2013       | SWI (20)   | F   | 11.6 ± 0.9   | 36 month follow-up| 2.3 ± 1.2  | DXA LSP        | BMC and BMD increased every year without differences between groups    |
|                                     | CG (20)    |     | 12.2 ± 0.8   |                    | 2.2 ± 2.2  |                |                                                                      |
| Narra et al. [79] 2013              | SWI (18)   | F   | 20.2 ± 2.6   | Retrospective     | 10.0 ± 3.8 | MRI FN         | No differences between SWI and the rest of the groups                |
|                                     | HIG (19)   |     | 21.3 ± 3.2   |                    | 9.8 ± 3.3  |                |                                                                      |
|                                     | ODD (19)   |     | 23.5 ± 5.1   |                    | 9.9 ± 4.0  |                |                                                                      |
|                                     | POW (17)   |     | 27.5 ± 6.3   |                    | 80.4 ± 47  |                |                                                                      |
|                                     | RUN (18)   |     | 28.9 ± 5.6   |                    | 12.4 ± 6.7 |                |                                                                      |
|                                     | CG (20)    |     | 24.1 ± 3.4   |                    | 2.9 ± 1.5  |                |                                                                      |

Notes: All differences between groups with statistical significance are in bold. Available online without a login are in italics. No significant differences were found between groups with aP value > 0.05. For the rest of the groups, p < 0.05 is in italics. aBMD = Areal bone mineral density; ALG = Active load group (swimming + waterpolo); Aprox = Approximately; ARG = Artistic gymnasts; B-ALP = Bone specific alkaline phosphatase; BA = Bone area; BAS = Basketball; BMC = Bone mineral content; BMAD = Bone mineral apparent density; BMD = Bone mineral density; BOD = Body builders; BR = Buckling ratio; BSJ = Bone strength index; CCS = Cross country skiing; CG = Control group; CG1 = Post-menopausal control group for less than 5 years; CG2 = Post-menopausal control group for more than 5 years; CLIM = Climbing; CRU = Collegiate runners; CRW = Crew; CSA = Cross-sectional area; CSSI = Cross-sectional moment of inertia; CTX = Type I collagen C-telopeptide; CYC = Cyclists; DIS = Discus throwers; DIV = Divers; Dpd = Deoxypyridinoline; ENU = Endurance runners; ESW = Endurance swimmers; F = Female; FHO = Field hockey; FKG = Fighting; FNECK = Femoral Neck; GYM = Gymnasts; HIG = High impact sports; HIL = High impact sports (soccer, volleyball); HSA = Hip structural analysis; ILG = Impact load group; IPTH = Intact parathormone; JAV = Javelin throwers; JUM = Jumpers; JUD = Judoists; LDR = Long distance runners; LSP = Lumbar Spine; M = Male; MED = Medium impact (running and field hockey); MET = Metatarsus; MIA = Multiple mixed activities; MOD = Moderate; MRI = Magnetic resonance imaging; NTX = Cross-linked N-telopeptides of type I collagen; OAT = Older athletes; OC = Osteocalcin; ODD = Odd impact sports; OPG = Osteoprotegerin; OTS = Other practiced sports; PIP = Procollagen type I C-peptide; PA = Physical activity; PINP = Procollagen type I N-terminal propeptide; Pyd = Pyridinoline; POW = Power lifters; REP = Repetitive impact sports (running); ROW = Rowing; RRU = Recreational runners; RUG = Rugby; RYG = Rhythmic gymnastics; RUN = Runners; SWI = Swimmers; SWI1 = Post-menopausal swimmers for less than 5 years; SWI2 = Post-menopausal swimmers for more than 5 years; SOC = Soccer; SED = Sedentary; SOF = Softball; SPA = Single photon absorptiometer; SPP = Sport games; SRU = Sprint runners; SSW = Sprint swimmers; SYS = Synchronized swimmers; THR = Throwers; TRA = Track; TEAM = Team sports; TEN = Tennis; TRI = Triathletes; TROCH = Trochanter; TSR = Track sprinters; VOL = Volleyball; V = Women; WB = Whole body; WBA = Weight bearing activities; WBE = Weight bearing sports; WLI = Weight lifters; WPO = Water polo; WTRI = Wards triangle; Z = Section modulus.
| Study                        | Participants | Study design | Training years | Training hours/week | Data source | Measured areas | Outcome                                                                 |
|------------------------------|--------------|--------------|----------------|--------------------|-------------|----------------|--------------------------------------------------------------------------|
| Liu et al. [75] 2003        | SWI (30)     | M-F          | Age at start of training M 19.8±1.9 F SWI 7.6±1.9 | 6.0         | pQCT Midtibia | No differences in vBMD of whole and cortical bone among the three male groups. |
| JUM (25)                    | SWI (19.8±1.3 F 19.9±1.4) | M 12.8±2.1 F 12.7±1.5 | 5.0         | In female SWI whole body and cortical vBMD was lower than CG |
| CG (25)                     | SWI (20.3±1.6 F 20.2±1.4) | M 12.8±2.1 F 12.7±1.5 | 5.0         | In female SWI periosteal area, endocortical area, PMI and SSL, where higher than CG |
| Nikander et al. [74] 2006   | SWI (20.6±2.8) | Case-control | 10.6±4.3        | 13.5±4.5         | pQCT Radius Tibia | No differences in distal tibia for BMC, PSM and cortical walls between SWI and CG |
| VOL (21)                    | SWI (21.2±3.0) | 8.6±3.3       | 9.9±2.5         | No differences at tibial shaft for BMC, CSA, PSM and cortical walls between SWI and CG |
| RAC (23)                    | SWI (23.6±4.5) | 9.6±3.5       | 4.6±3.9         | SWI showed higher humeral CSA than CG |
| SOC (18)                    | SWI (21.4±3.0) | 10.7±3.8      | 8.6±5.5         | SWI showed higher cortical BMD at tibial shaft than VOL |
| CG (30)                     | SWI (24.3±3.1) | 2.9±2.0       | Calcium intake  | No differences in calcium intake among groups |
| Shaw et al. [73] 2009        | SWI (21.9±2.5) | Case-control | 10.3±2.9        | 13-15 years 9.1±5.1 | pQCT Humerus Radius Ulna | SWI showed higher resistance to TD,CA,Imax than CG for the dominant humerus |
| CRI (16)                    | SWI (22.0±2.5) | 11.6±2.3      | 13-15 years 14.9±7.6 16-19 years 20.8±10.7 | SWI showed greater TA than CG for the dominant humerus |
| CG (20)                     | SWI (21.6±4.7) | 11.0±2.3      | 13-15 years 14.9±7.6 16-19 years 20.8±10.7 | SWI showed higher resistance to Imax, Im, CA, TD and TA than CG for the non-dominant humerus |
| Nikander et al. [76] 2010   | SWI (20.2±2.6) | Case-control | 10.0±3.8        | 17.2±5.6         | pQCT Distal tibia Tibial shaft | No differences between SWI and CG for the distal tibia |
| HIG (64)                    | SWI (21.3±3.2) | 9.8±3.3       | 11.8±2.8        | SWI showed lower BMC and CoA than RUN, ODD and HIG for the distal tibia |
Table 2. Cont.

| Study | Participants | Sex | Age (years) | Training years | Training hours/week | Data source | Measured areas | Outcome |
|-------|--------------|-----|-------------|----------------|--------------------|-------------|----------------|---------|
| ODD (60) | 23.5 ± 5.1 | 6 |
| POW (17) | 27.5 ± 6.3 | 6 |
| RUN (18) | 28.9 ± 5.6 | 6 |
| CG (50) | 24.1 ± 3.4 | 6 |

- SWI showed lower total CSA than HIG for the distal tibia
- SWI showed lower PSM than HIG and ODD for the distal tibia
- No differences between SWI and CG for the tibial shaft
- SWI showed lower BMC than POW, ODD and HIG for the tibial shaft
- SWI showed lower CoA, PSM and total CSA than RUN, ODD and HIG for the tibial shaft

ACT = Average cortical thickness; BMD = Bone mineral density; CA = Compression; CG = Control Group; CoA = Cortical area; CRI = Cricketers; CSA = Cross-sectional area; F = Female; HIG = High impact exercises; Imax = Bending deformation in the maximum plane; Imin = Bending deformation in the minimum principal plane; JUM = Jumpers; M = Men; ODD = Odd-impact exercises; PMI = Polar moment of inertia; POW = Power lifting; PSM = Polar Section Modulus; RAC = Racket sports; RUN = Endurance running; SSI = Strength strain index; SWI = Swimmers; TA = Total bone area; TD = Torsional deformation; vBMD = Volumetric bone mineral density; W = Women.

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Table 3. Studies using ultrasound.

| Study            | Participants          | Study design | Training years | Training hours/week | Data source | Measured areas | Outcome                                                                 |
|------------------|-----------------------|--------------|----------------|---------------------|-------------|----------------|-------------------------------------------------------------------------|
| Taaffe et al.    | SWI & WPO (10)        | Case-control | Began at 14    | 12                  | Ultrasound  | Calcaneus      | Ultrasound attenuation determined by QUS was not significantly different among groups |
| [41] 2001        | M                     | 25.5 ± 5.6   |                |                     | SPA         |                |                                                                         |
| JUM (10)         | 24.9 ± 3.9            | Began at 14  | 12             |                     |             |                |                                                                         |
| CG (10)          | 27.7 ± 7.3            |              |                |                     |             |                |                                                                         |
| Falk et al.      | SWI (21)              | Case-control | > 1.5          | 7.8 ± 3.4           | Ultrasound  | Radius Tibia   | SWI showed lower mean radial SOS values than GYM                       |
| [89] 2003        | F                     | 11.0 ± 0.9   |                |                     |             |                |                                                                         |
| GYM (25)         | 10.0 ± 0.7            | > 1.5        | 4.2 ± 1.7      |                     |             |                | SWI showed higher tibial SOS values than CG                            |
| CG (21)          | 10.1 ± 1.1            | Physical activity twice per week |               |                     | Calcium intake |                | No differences were observed between groups in calcium intake.          |
| Falk et al.      | SWI (61)              | Case-control | > 1.5          | SWI trained 2 to 6 times per week | Ultrasound  | Radius Tibia   | SWI and CG had similar radial SOS                                      |
| [88] 2004        | F                     | 15.9 ± 4.9   |                |                     |             |                |                                                                         |
| CG (71)          | 15.0 ± 4.0            | CG ≥2 times per week |                |                     | Calcium intake |                |                                                                         |
| Yung et al.      | SWI (15)              | Case-control | ≥2             | ≥4                  | Ultrasound  | Calcaneus      | All QUS parameters were higher in exercise groups compared with the control group |
| [90] 2005        | M                     | 20.9 ± 1.3   |                |                     |             |                |                                                                         |
| SOC (15)         | 21.2 ± 1.7            | ≥2           | ≥4             |                     |             |                | SWI showed lower BUA, and stiffness index scores than SOC and DAN       |
| DAN (10)         | 20.6 ± 0.7            | ≥2           | ≥4             |                     | Calcium intake |                | No differences in calcium intake among groups                           |
| CG (15)          | 21.3 ± 1.2            |              |                |                     | Calcium intake |                |                                                                         |
| Falk et al.      | SWI & WPO (89)        | Case-control | > 1.5          | 4.5–22              | Ultrasound  | Radius Tibia   | Radial SOS measures did not differ between athletes and nonathletic controls |
| [88] 2007        | M                     | 8–23         |                |                     |             |                |                                                                         |
| SOC (97)         | 8–23                  | > 1.5        | 4.5–22         |                     |             |                | SWI showed higher tibial SOS values than CG                            |
| CG (80)          | 20.6 ± 0.7            | ≥2           | ≥4             |                     | Calcium intake |                | No differences were observed between the SWI and SOC in any of the age groups |
| Velez et al.     | SWI (43)              | Case-control | –              | –                   | Ultrasound  | Calcaneus      | Reported calcium intake was low in all groups                           |
| [39] 2008        | M-F                   | 72.6 ± 6.8   |                |                     |             |                |                                                                         |
| RUN (44)         | 73.3 ± 7.1            |              |                |                     |             |                | SWI showed lower calcaneal stiffness index than RUN                      |
| CG (87)          | 75.3 ± 5.4            |              |                |                     | Calcium intake |                |                                                                         |
| Ludwa et al.     | SYS (20)              | Case-control | –              | SY5±6               | Ultrasound  | Radius Tibia   | No significant differences between SWI and CG in radial and tibial SOS values |
| [87] 2010        | F                     | 15.3 ± 1.2   |                |                     |             |                |                                                                         |
| CG (20)          | 15.2 ± 1.1            | Bone markers |                |                     | Calcium intake |                | SYS had lower IGF-I concentrations than CG                              |
| Velez et al.     | SWI (43)              | Case-control | –              | –                   | Ultrasound  | Calcaneus      | SWI showed lower calcaneal stiffness index than RUN                      |
| [39] 2008        | SY5±6                 | 72.6 ± 6.8   |                |                     |             |                |                                                                         |
| RUN (44)         | 73.3 ± 7.1            |              |                |                     |             |                | SWI showed lower calcaneal stiffness index than RUN                      |
| CG (87)          | 75.3 ± 5.4            |              |                |                     | Calcium intake |                |                                                                         |
| Study                  | Participants | Study design | Training years | Training hours/week | Data source | Measured areas | Outcome                                                                 |
|-----------------------|--------------|--------------|----------------|---------------------|-------------|----------------|--------------------------------------------------------------------------|
| Shenoy et al. [91]    | SWI (40) M-F | Case-control | 22.4±1.7       | 9.1±3               | Ultrasound  | Radius Tibia  | SWI showed lower mean dominant radial, and both dominant and non-dominant tibial SOS than SOF. |
|                       | SOF (40)     |              | 21.9±1.7       | 8.3±3               |             |                | SWI showed higher dominant tibial SOS than the CG                        |
|                       | CG (40)      |              | 22.5±1.9       |                     |             |                |                                                                          |
| Czeczuk et al. [49]   | SWI1 (11) F  | 12 month follow-up | 52.1±3.3 | Currently not swimming | Ultrasound Calcium intake | Calcaneus LSP | SWI1 showed higher stiffness index values than SWI2                        |
|                       | SWI2 (7)     |              | 63.3±4.3       | Current PA 6.3      |             |                |                                                                          |
|                       | CG1 (11)     |              | 50.7±2.2       | Current PA 1.4      |             |                |                                                                          |
|                       | CG2 (7)      |              | 60.6±2.3       | Current PA 0.6      |             |                |                                                                          |

Calcium intake: No differences in daily calcium intake among groups although both were below the recommended daily intake.
swimming practiced in adulthood or elderly stages of life, may reduce the rate of normal bone mass loss accompanying age [42,43,45], although it is unclear if this is a real direct effect of swimming or it is due to a more active lifestyle. Quality assessment suggests a medium quality level of the literature on this subject. Longitudinal studies and well controlled case-control studies including past physical activity history are needed to elucidate the independent effect of swimming in bone development and evolution from childhood to late adulthood.

1.2 Bone geometry and structure. Bone strength is determined by BMD and bone geometric properties [69–71]. However, despite the fact that the use of pQCT allows volumetric (vBMD) to be measured, distinguishes between different bone sections and their respective BMD, and is independent of physical size [72], to our knowledge only 4 studies have used this technique in swimmers [73–76] (Table 2). To ascertain whether the mechanical properties of bone in response to long-term physical exercise are related to geometric adaptation and not to vBMD in swimmers as they are in jumpers and tennis players [74,77,78] would seem to be an important area of study. In order to determine this, bone could be evaluated with pQCT or using DXA combined with other techniques such as magnetic resonance imaging (MRI) [31,79] or hip structural analysis (HSA) [14–17,67].

A basic means of studying bone structure is by performing a radiography as Xia Qu Ma [80] did in 1992. He performed a radiograph of the anterior side of both humeri and measured length, cortical thickness and diameters at the proximal, middle and distal thirds finding that swimmers had the lowest medial and lateral cortex at both humeri of all the sport groups compared, and that they presented similar values to the CG. Further studies also measured swimmers humeri [73,74], tibia [74–76] and femur [79] with different devices revealing similar [16,76,79] or higher cortical cross-sectional areas (CSA) and bone strength indexes [14,73,75] in swimmers than in CG. The 3 studies using pQCT that found an improved structure in swimmers than CG were all performed in the same sample age groups, young adults (20 years old). When HSA was used to evaluate bone structure, adolescent [16,17] or adult [67] (10–35 years old) swimmers presented values similar to CG. These different results could be due to different age samples or to differences between imaging techniques. However, when compared with other sports, swimmers had lower cortical thickness [17,74,75], cortical CSA [17,71,75,76] and lower strength indexes [31,67,75,76]. Results were similar independently of the technique used: pQCT [73–76], MRI [31] or HSA [14,17,67]. The lower cortical mass described in some studies allows a larger medullary cavity CSA in swimmers, resulting in lower trabecular vBMD as found by Nikander et al. [74] and Duncan et al. [31], and a bone with its mass distributed relatively distally from the centroid.

Similar results were found when bone geometry was assessed by Liang et al. [81], using a totally different technique: the mechanical response tissue analyzer (MRTA), invented for the National Aeronautics and Space Administration (NASA) to evaluate bone strength in astronauts after space flight, using the response of a long bone to a low-frequency vibratory stimulus. Results showed that although synchronized swimmers exhibited lower BMD (calculated with a single photon densitometer) wrist values than GC and SG, the bone bending stiffness in the tibia and ulna were greater in synchronized swimmers than in the CG, reinforcing the fact that structure has a great influence on bone strength independently of BMD.

Ferry et al. [15] compared bone geometry during an 8-month period in swimmers and soccer players finding that swimmers did not increase sub-periosteal width, while soccer players did, as well as bone strength indexes such as the cross-sectional moment of inertia and section modulus Z-scores. Buckling ratio (BR) which is an index of bone instability (BR = maximum distance from the center of mass to the medial or lateral surface divided by the cortical thickness), was the only value improved in swimmers and maintained in soccer players. BR still remained higher in swimmers after the longitudinal period suggesting that swimmers had weaker bone.

In summary, although swimmers may show weaker bone when compared to other weight-bearing sports as a result of smaller cross-sectional areas, the characteristics of the sport may adapt the bone to a higher trabecular CSA [31] and similar [16,17,67,76,79] or higher bone strength indexes [73–75,81] when compared to a sedentary group, making it more resistant to bending and torsion than a sedentary bone, even though it may have lower BMD. However, studies including both methods of assessment, DXA with HSA and pQCT or MRI, and different sample age groups should be performed in order to test this hypothesis.

1.3 Stiffness, speed of sound and broadband ultrasound attenuation. The use of quantitative ultrasound (QUS) is an option that avoids results biased by differences in body size among subjects. The values of SOS, BUA, and the Stiffness index (SI) derived from both of the former, provided by the QUS, are related to bone density and structure [82] but not to cortical thickness [83]. SI is the default parameter used by the manufacturer for demographic comparison of patient data because SOS and BUA are given as absolute values with no normative values for them. Thus T-scores for these two parameters cannot be calculated [84,85].

Taaffe et al. [41] compared swimmers with jumpers and a CG observing no differences among the 3 groups in BUA. Similar values between swimmers and other SG were found in only one

| Table 4. Studies using MRTA. |
|---|
| Study | Participants | Study design | Training years | Training hours/week | Data source | Measured areas | Outcome |
| Liang et al. [81] 2005 | SYS (13) F | Case-control | 10.4±0.5 | 36 | MRTA | Tibia Ulna | El from the ulna and tibia in each group of athletes was greater than in the CG. |
| GYM (8) | 20±0.4 | 13.9±0.6 | 20 | | | | SYS showed lower wrist BMD than GYM and CG |
| CG (16) | 22±0.1 | | | | | | |

El = Bone bending Stiffness; CG = Control group; GYM = Gymnasts; MRTA = Mechanical response tissue analyzer; SYS = Synchronized swimmers.

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EI = Bone bending Stiffness; CG = Control group; GYM = Gymnasts; MRTA = Mechanical response tissue analyzer; SYS = Synchronized swimmers.
other study [86]. However, a lack of differences between swimmers and CG was also found in two further studies [35,87]. In contrast, Falk et al. [86,88,89] observed higher tibial SOS values in both male and female swimmers than in the CG in their 3 studies; as others [90,91] did. Despite the above findings, some of these studies included a SG and with further studies showed that either children [89], adults [90,91] or elderly [35] swimmers presented lower values than their high impact comparison groups. Showing in 2 of the previous studies lower SI values in swimmers than SG [35,90].

To our knowledge only one longitudinal 12 month follow-up study using QUS has been performed in swimmers [49]. The study sample was composed of former postmenopausal swimmers that were not swimming when the study took place. Swimmers showed a lower decrease in SI values than CG, although they performed more current physical activity (other than swimming). Therefore it is not possible to confirm that the lower SI decrease was due to swimming (in earlier stages of life) or was a consequence of current physical activity.

We can briefly conclude that swimmers have higher QUS values than CG although these values seem to be higher in high impact sports than in swimmers. It is worth noting that the higher QUS values in swimmers when compared to CG were generally present in the lower limbs. However, the major forces applied in some swimming styles such as crawl or backstroke are applied with the upper limbs. This would suggest that the higher QUS values presented by the swimmers but not by the synchronized swimmers [97], might be due to the push that swimmers perform against the wall, although future studies should be performed comparing swimmers with similar training and history habits who train in a 25 and 50 meter pool to compare their lower limb QUS values.

1.4 Bone markers. Bone is a metabolically active tissue that is constantly changing, with BMD being the result of bone formation and resorption which are closely linked in time and space within the bone multicellular unit [92]. To assess these changes we can measure bone turnover markers which are usually able to provide an early indication of an effect on bone and can be quite sensitive, their main limitations being poor specificity of response and lack of validated connection with the functional outcome [93].

Regarding bone formation markers, several studies showed higher bone-specific alkaline phosphatase (B-ALP) values in swimmers than in CG [47] and SG [40,47,94]. However, Morgan et al. [59] found lower values of B-ALP in swimmers than in high impact sports. These diverse results may be due to the fact that the sample ages of the studies were adolescents [47], 20 year old adults [59,94] and 30 year old adults [40]; all stages of life with different bone dynamics. Another bone formation marker used is osteocalcin (OC), that was lower [57], similar [16,17,28,59,87] or higher [40] in swimmers than in CG and lower [57] or similar [17,40,59] when compared to SG. These differences between studies are a clear example of the difficulties inherent in the use of biochemical markers owing to the wide range of interactions possible depending on age, gender, nutritional status, season and time following intense training [95,96]. Added to these difficulties and as described by PASSCLAIM [93], the OC molecule exhibits considerable immunological heterogeneity. This, combined with the fact that no internationally recognized assay standard exists, make OC measurements difficult to interpret meaningfully. This may be one of the explanations of the heterogeneity of this bone marker in swimmers.

The use of two bone markers to evaluate bone formation [17,40,59] permits differing results to be compared and is therefore a recommended methodology to follow for future studies.

Regarding bone resorption, Cross-linked N-telopeptides of type I collagen (NTx) was the most used biomarker [57,59,87], showing no differences between swimmers, CG and other SG. Other resorption markers used were pyridinoline and deoxypyridinoline both lower in male swimmers than judo athletes [94] and higher than CG [47]. Type I collagen C-telopeptide (CTX), another resorption marker that has been recommended by the International Osteoporosis Foundation and the International Federation of Clinical Chemistry [1] was similar [16,17] or higher in swimmers when compared to CG [40]. This latter point, added to the previously named higher B-ALP values, suggests a higher bone turnover in swimmers than in controls which reflects an intense remodelling process without producing any differences in BMD. Perhaps the use of other techniques to assess bone quality or structure such as pQCT might have shown differences among bones and therefore explained the differences revealed among bone markers.

The Osteoprotegerin(OPG)/Rank-ligand (RANKL) system which is known to have considerable influence on bone formation and degradation, has only been evaluated in one study [17], that showed lower levels of RANKL in swimmers than in gymnasts and controls. Further studies evaluating OPG and RANKL in swimmers are needed in order to confirm these results and elucidate the effect that swimming might have on this system.

Summarizing all the previous studies that include swimmers and bone metabolic markers we can conclude that swimming seems to involve a high bone turnover [40,47,94] although in most cases this is not translated into higher BMD. Out of the 14 studies included in this review including bone metabolic markers, only one [87] was performed with a technique other than DXA; QUS, which showed no differences between QUS parameters or bone metabolic markers between swimmers and CG, suggesting that bone metabolic markers might have a high relation to bone structure. Moreover, Mamoun et al. have performed HSA in two recent studies [16,17] finding no differences in bone markers nor bone structure between swimmers and CG, thus reinforcing the previous hypothesis. However, further studies including bone metabolic markers and techniques which allow the evaluation of bone structure are needed in order to confirm this hypothesis.

2. Factors affecting bone mass

2.1 Hormonal profile. It is well known that hormone concentrations change during growth and vary during or after the practice of exercise[97,98]. In addition, some parameters of the hormonal profile affect bone metabolism; for example estrogens have been demonstrated to stimulate the proliferation of osteoblasts [99] and insulin-like growth factor-I (IGF-I) has been shown to activate bone turnover [100]. It is therefore important to describe whether hormone concentrations were similar in swimmers and CG or SG.

Lima et al. [47] first found lower testosterone (TT) values in swimmers than in high impact athletes. However, when compared to other non-impact athletes such as cyclists, swimmers showed higher values of TT. Comparison with CG exhibit inconclusive results showing lower [27], and similar [16,39] values in swimmers. These differences could be due to different training loads as previously suggested by others [101], or due to the different age-range in the samples of the studies [27,39].

Estriadiol levels were also studied, with no differences found between young swimmers, CG and other sports [39]. A similar case is the Luteinizing hormone that was also measured in three studies and also revealed no differences in values between
swimmers, CG and other sports in adolescents [16,47] and adults [39].

Ju¨rimae et al. focused on the influence of Ghrerin (GR) on BMD, showing that GR appeared to be an important hormonal predictor for BMD in swimmers [27]. However, in a further study they showed that GR was not related to measured BMD values in swimmers, suggesting that GR concentration did not have a direct influence on bone mineralization in female swimmers [102].

Ju¨rimae et al. [27,102], also studied leptin which is directly related to fat mass as well as to BMD in children and adolescents [103,104] finding similar values in swimmers, GC and sport reference values. Further studies [36] also found similar values in swimmers suggesting that leptin concentration in swimmers is not related to bone mineral parameters.

IGF-I which stimulates endochondral bone formation and activates bone turnover [100] was lower in swimmers than in CG [87] and lower increases during pubertal development were found in a further longitudinal study [27]. However in the latest published study regarding IGF-I, swimmers and CG presented similar values [16].

We can therefore conclude that the values of the majority of the hormones studied were similar in swimmers and CG. However, the concentrations of some of these hormones may vary according to training loads, making the measuring period critical regarding hormone concentrations and associated effects.

2.2 Calcium intake. Most of the studies that registered calcium intake showed no differences among groups. Eighth studies showed significantly higher calcium intake values in swimmers than in CG [14,15,32,34,35,40,49,105]. Calcium is closely related with bone mass and its intake through diet is crucial. According to the recommended dietary allowance guidelines [106] the studies performed on children [23,25,66,89], adolescents [14,15,31,33,34,47,86,88], young adults [86,88,90] and older adults [37,44,49] indicate that swimmers did not reach the recommendations established by these guidelines for calcium intake. However, some of these studies showed higher BMD than reference values independently of calcium intake.

Research has demonstrated that calcium supplementation increases bone mass significantly during childhood and adolescence [107,108]. A bone-exercise-nutrition interaction exists as shown in previous studies [109]. It would therefore be interesting to perform specific studies evaluating the effect of calcium intake in swimmers in order to ascertain the possible interactions between physical activity, calcium and bone. Other nutritional aspects like magnesium, phosphorus or vitamin D that have not been registered and also affect bone may also be important regarding results. We would therefore suggest that future studies evaluating bone take these variables into account.

2.3 Gender. Gender differences in peak bone mass acquisition are well documented in humans [110], it is therefore important to describe whether swimming might affect these differences.

It seems that results in studies with either male or female participants are similar. Some studies included both genders showing no differences between groups [32,94]. However, Orwell et al. [43], who first included both male and female swimmers, and a further study [28] observed higher BMD values in male swimmers than in CG, whereas female swimmers showed similar bone values to the CG. As previously commented, these exclusive differences for the male group were thought to be due to the greater forces generated by males resulting in a greater effect on bone remodelling. On the contrary, Grimston et al. [55] found lower bone mass values only in male swimmers when compared to CG. Different values between genders were also found by Liu et al. [75] that showed higher periosteal area, polar moment of inertia and strain strength index only in female swimmers when compared to CG. These higher values only in females could be due to delayed puberty that results in larger periosteal and endocortical area in girls but not in boys [73], female swimmers having the latest menarche in the study and therefore a later puberty. Similar results were found in another study [46] where female swimmers showed higher arm BMD; however, these differences were inexistent between males.

2.4 Age. We have observed that swimming does not seem to negatively affect bone mass and might provide a stronger bone structure than that of the CG, but weaker than that of other impact sports independently of the age group studied: children, adolescents or adults. However, as previously stated, it seems that swimming might be more beneficial later in life. Of the 5 studies performed with DXA that found benefits of swimming compared to CG, 4 were performed in adults over 40 years old, suggesting that swimming may be a beneficial activity to practice in later adulthood in order to maintain bone. It is possible that these higher bone mass values in this older population were due to a more active life than their CG, as found in some studies [49]. Therefore, it would be interesting to take into account in future studies other sports practiced, in addition to swimming, to explain whether the differences within groups might be due to other activities or whether they are exclusive to swimming.

2.5 Training influence. The number of years practiced and weekly hours trained could influence bone in different ways. Unfortunately, this information is not available in all the articles included in this review. Weekly training hours were therefore evaluated when specified by the authors and no evidence of its influence on bone mass was found, in fact, the data presented in each article regarding weekly training hours and years of practice were not clearly specified and therefore cannot be taken into consideration. Training intensity may also differ between groups that perform the same sport modality and train for a similar number of hours. Different intensities can result in different sport performances and also in different body composition and bone adaptations. Magkos et al. [51] were the only researchers that divided swimmers into sprint and endurance swimmers, finding lower BMD values in the latter. The higher BMD values of the sprinters could be due to the higher muscle force and as a result home stimulation that sprinters perform during training and competition. However, future studies comparing groups that have different training routines should be performed to throw more light on this question.

In addition to swimming hours, many swimmers also perform strength training that could also affect bone. This type of training was generally not reported in most of the studies included in this review. However, due to the osteogenic effect that this type of training has, it is important that future studies evaluating bone in swimmers take this parameter into account.

3. Limitations

The current systematic review excluded non-English and non-Spanish publications; therefore a possible language bias appears. The included studies were too heterogeneous to perform a meta-analysis. The lack of this type of analysis makes it difficult to obtain strong conclusions. Although tables 1, 2, 3 and 4 contain quantitative information on each individual study the classification of the articles according to their bone evaluation method (DXA, pQCT, QUS and MRTA) is not a closed issue.
Conclusions

Although few studies found lower BMD in swimmers when compared to sedentary controls most of the research shows similar BMD for both groups independently of the age group, except for later adulthood where swimmers presented lower bone mass decrease than sedentary controls, although it is not clear if these differences are sport-specific or are due to the more active life-style reported in swimmers. It would therefore appear that swimming does not negatively affect bone mass. Swimmers mostly showed lower BMD values than any other SG independently of the age of the sample. In fact, longitudinal studies showed lower BMD increases during a season in this specific sport-group. Nevertheless, swimmers showed higher bone turnover values than sedentary controls that were not reflected in higher BMD. This higher bone turnover seems to be associated with a more efficient bone structure of swimmers which appears to be weaker when compared with high impact sports and stronger when compared to sedentary controls, independently of the method of analysis. Many factors may interfere in the effect of swimming on bone, although no differences among groups were found in some of them such as hormone concentrations or calcium intake, the influence as confounders of these factors has not been elucidated.

Perspective

There are 3 relevant remaining questions:

- How many hours per week, years of practice and intensity of training are needed in order to obtain this structure?
- Is it possible to obtain this improved structure at any stage of life, or is it only possible during childhood and/or adolescence?
- How long does this structure perdure without activity?

Future research is needed to ascertain some of these questions and establish structural benefits of swimming on bone tissue. It is also noteworthy that swimming presents lower risks of traumatic fracture than other high impact sports, it is beneficial for cardiovascular fitness [111], and has an important role not only in the promotion of well-being but also in the improvement of muscle strength, which can prevent falls and resulting fractures [112]. Therefore if the previous questions were answered in a positive way, swimming may be a highly beneficial sport to practice regarding bone health.

Future studies in this area should take into consideration the following aspects:

1. Evaluation method should include:
   a. Imaging techniques: Two techniques should be employed in each study. DXA is essential and a second method of the researchers choice to evaluate bone structure, preferably pQCT or MRI.
   b. Bone metabolic markers: To evaluate metabolic activity and view bone remodeling process.

2. Physical activity register

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a. Accelerometry: In order to evaluate physical activity objectively.

b. Questionnaires: To evaluate past and current physical activity. This might be of extreme importance in studies performed in adults or elderly population.

3. Diet

To evaluate calcium, phosphorus and vitamin D intake in addition to total energy intake and other nutrients that might affect bone and body composition is of crucial importance.

4. Other confounders

a. Type of swimming: It is important to distinguish, if possible, between sprint swimmers and long distance swimmers due to the fact that they might present different types of training routines and these might involve different types of efforts that might affect bone in a different way.

b. Years of practice, and weekly hours trained: Particularly when performing a study that compares sport disciplines.

c. Complementary weight work: Many swimmers perform weight training in order to improve their performances. This should also be registered and taken into account in future studies.

d. Point of the season: Training loads change according to the season period and this might affect bone that is constantly adapting. When performing studies that compare sports, evaluation should take place in similar load pattern periods of the different sports.

e. Tanner stage: When performing studies with children or adolescents, tanner stage should always be registered as differences in bone might be partly due to maturational status.

f. Menstrual status: This is another important variable to take into account due to the close relation that it has with bone.

Supporting Information

Table S1 PRISMA Checklist. (DOC)

Table S2 Quality assessment tool of the cross-sectional included studies. (DOCX)

Table S3 Quality assessment tool of the included longitudinal studies. (DOCX)

Author Contributions

Conceived and designed the experiments: JAC GVR. Performed the experiments: AGB AGA AGC. Analyzed the data: AGB AGA AGC. Contributed reagents/materials/analysis tools: AGB AGA AGC JAC GVR. Wrote the paper: AGB AGA AGC JAC GVR.
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